NASA

SECTION 8

Summary and Conclusion

- Impact analysis ("Crater") indicates potential for large TPS damage
  - Review of test data shows wide variation in impact response
  - RCC damage limited to coating based on soft SOFI
- Thermal analysis of wing with missing tile is in work
  - Single tile missing shows local structural damage is possible, but no burn through
  - Multiple tile missing analysis is on-going
- M/OD criteria used to assess structural impacts of tile loss
  - Allows significant temperature exceedance, even some burn through
    - Impact to vehicle turnaround possible, but maintains safe return capability

Conclusion

- Contingent on multiple tile loss thermal analysis showing no violation of M/OD criteria, safe return indicated even with significant tile damage

Michele Lewis

From:	Christensen, Scott V [Scott.V.Christensen@boeing.com]
Sent:	Tuesday, January 21, 2003 10:26 AM
To:	Burghardt, Michael J; Norman, Ignacio; Chao, Dennis C; Parker, Paul A; Moon, Darwin G; Dunham, Michael J; Bell, Dan R; EXT-Madera, Pamela L; KOWAL, T. J. (JOHN) (JSC-ES3) (NASA)
Subject:	FW: STS-87/89 Info

87DAMAGE.PDF sts89frr.ppt

Here is some of the stuff we did before that matches up with a similar type of scenario. My memory on this was we were working on large amounts of foam coming the intertank due to a foam material change. I recall one additional briefing from Jerry Warren that I don't have yet.

-----Original Message-----
From: Bell, Dan R
Sent: Tuesday, January 21, 2003 8:44 AM
To: Christensen, Scott V
Subject: FW: STS-87/89 Info

Scott,
I wanted to make sure you had copies of these charts. Robert also found a copy of the foam impact testing conducted in 99 but does not have a electronic copy. I think Paul Parker was going to contact Mike Koharchik, he may have an electronic copy. I invited Michelle to join our 11:00 meeting. The HB background and data should be utilized for this effort.

Dan

-----Original Message-----
From: Chaffey, Michele L [mailto:michele.l.chaffey@boeing.com]
Sent: Tuesday, January 21, 2003 9:25 AM
To: Bell, Dan R
Subject: STS-87/89 Info

Here is the briefing and IL I sent out with the STS-87/89 info. The IL has
a little more technical detail about the analyses performed.
<<87DAMAGE.PDF>>
<<sts89frr.ppt>>

Michele Chaffey
Orbiter Aero/Thermal Analysis
NASA Systems
(714)372-0261

OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998

Observation:

- An Unusual Number of Damaged Tiles Was Observed on OV-102

Concern:

- Potential Temperature or Margins Violations on OV-102
- Potential of Similar TPS Damage on Next Flight OV-105 (STS-89)

Discussion:

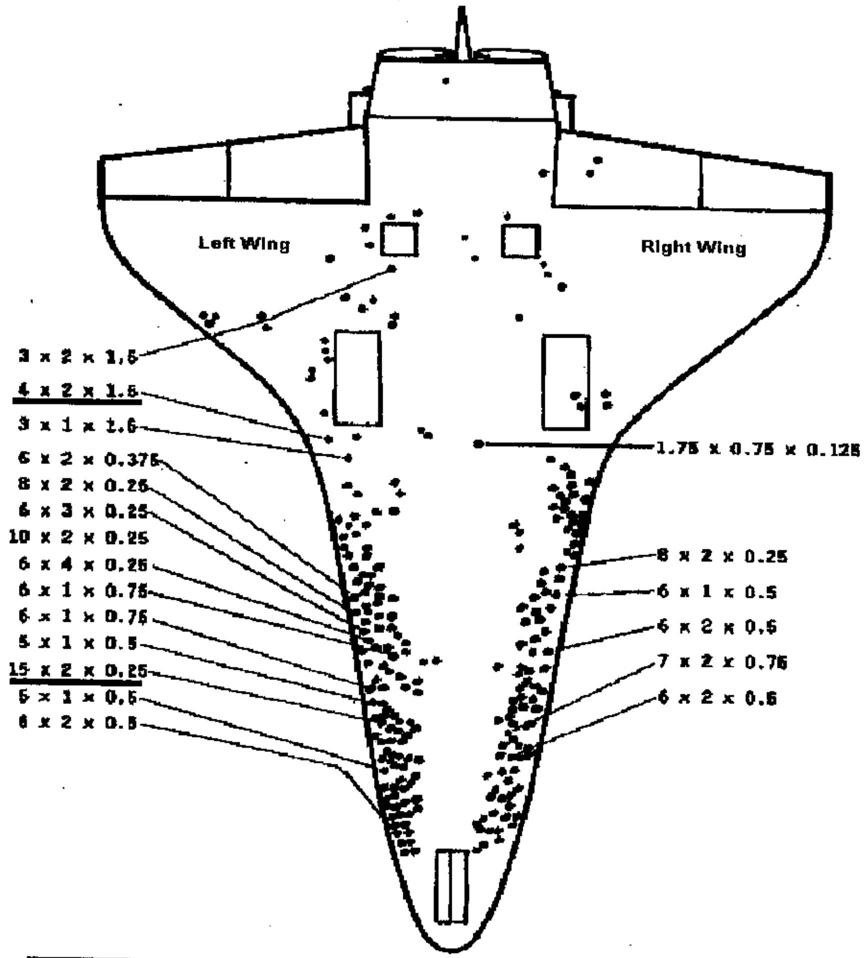
- OV-102 TPS Sustained a Total Of 308 Hits During STS-87
  - Lower Surface had 244 Hits with 109 Hits > 1" in Length
- Major Damage Area on the Lower Surface Is Between the Nose Landing Gear and Main Landing Gear Doors
  - Largest Damage Located on the Glove Measuring 15"x 2"x.25"
  - Deepest Damage Located Forward of Left Main Gear Door Measuring 4"x 2"x1.5"

OV-102 (STS-87) TPS Damage

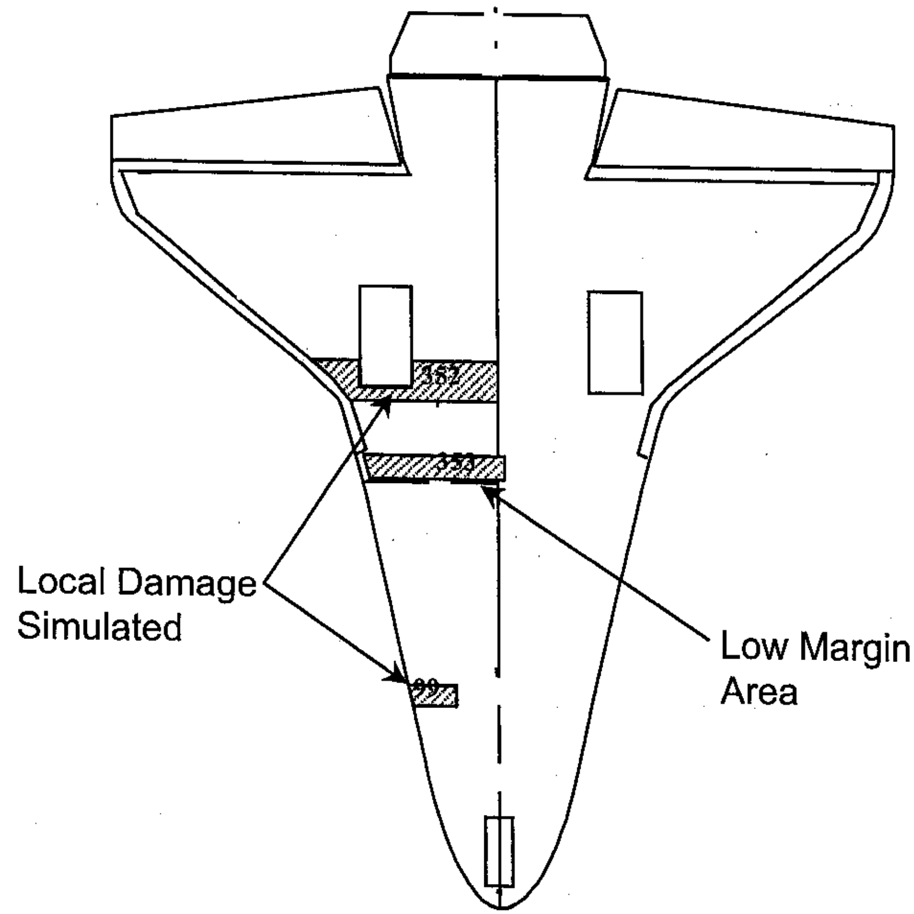
Presenter
R. Gatto

Date
January 6, 1998

Lower Surface Tile Damage



Thermal Math Model (TMM)
Locations



OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998

Actions Taken To Evaluate STS-87:

- Evaluated the Impact of TPS Damage on OV-102 STS-87
  - Reviewed Flight Data - OI, MADS, Physical Conditions
  - Identified and Removed Tiles and Inspected Structure Under Tiles
  - Performed Thermal/Structural Analysis at TPS Damage Sites
    - Simulated Local TPS Damage at Two Worst Sites and Estimated TPS and Structural Temperatures

Results of STS-87 Evaluation:

- Actual STS-87 Damage Was Determined to be Limited to TPS
  - Flight Data and Tile Removal/Inspection Found No Structural Damage
  - Analysis Simulation Indicates Damage Limited to TPS
    - Analysis Correlates with Observed TPS Surface at Damage Sites Being Near and Just Above Melting Temperatures
    - Structure Temperatures Would Not Exceed Acceptable Limits
- 101 Tiles Are Being Replaced on OV-102

OV-102 (STS-87) TPS Damage

Actions Taken To Evaluate STS-89:

- Evaluated Impact of Two Potential Damage Scenarios on STS-89
  - Evaluated Local TPS Damage As Seen on STS-87 But With Impact at More Critical Locations Within the Observed Flow Path
    - Impact at Thin Tile Location Has Tile Loss Down to Densified Layer
  - Evaluated Potential Reduction on Safety Margins if STS-89 Tile Damage Is More Severe Than STS-87 Experience
    - Identified Critical Margin Concern Is Bottom Panel Temperature Gradients - Extensive Efforts Over the Years to Install Heat Sink Material to Make Gradients As Mild As Possible
    - Simulated 25% Tile Damage Over One Frame Bay of Bottom Panels

Results of STS-89 Evaluation:

- Local Damage Similar to STS-87 Experience at Thin Tile Locations Would Have Safe Vehicle Return But With Possible Local Structural Repairs
  - Tile Loss Down to Densified Layer Gives Local Peaks to 500F with Possible Structural Repair - Adjacent Structure Picks Up Load for Safe Vehicle Return

OV-102 (STS-87) TPS Damage

Presenter
R. Gatto

Date
January 6, 1998

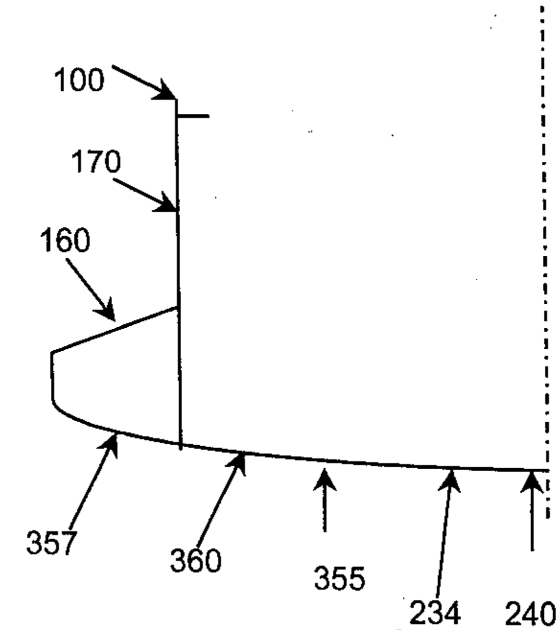
Results of STS-89 Evaluation, Cont.:

- Simulation with Damage More Severe than STS-87 Significantly Degraded Safety Margins
  - 25% Decrease in Tile Thickness in Out Board Panels Gives Large Increase in In-Plane Gradients and Thermal Stresses
  - Cannot Achieve Required 1.40 Factor of Safety - Approximate Contingency Capability Is:

    TAEM - F.S. = 1.0 at 1.8 g's

    Land - F.S. = 1.2 at 5.5 feet/sec

    = 1.4 at 3.0 feet/sec



CONCLUDE - With Hypothesized Damage (Second Scenario), Factor of Safety Will Be Less Than 1.0

OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998

Conclusions:

- STS-87
  - No Local Temperatures Exceeding Structural Temperature Limits
  - Safety Margin of 1.40 Not Violated
- STS-87 Severity of Impacts on STS-89 Would Have Safe Vehicle Return But With Possible Local Structural Damage
  - Possible Structural Temperature Peaks to 500F in Thin Sandwich Parts Could Require Local Structural Repair
- Potential STS-89 Damage More Severe than STS-87 Could Significantly Degrade Safety Margins
  - Wider Area of Impact Damage on Bottom Panels Results In Unacceptable Margins

Backup

OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998

Results of STS-87 Evaluation:

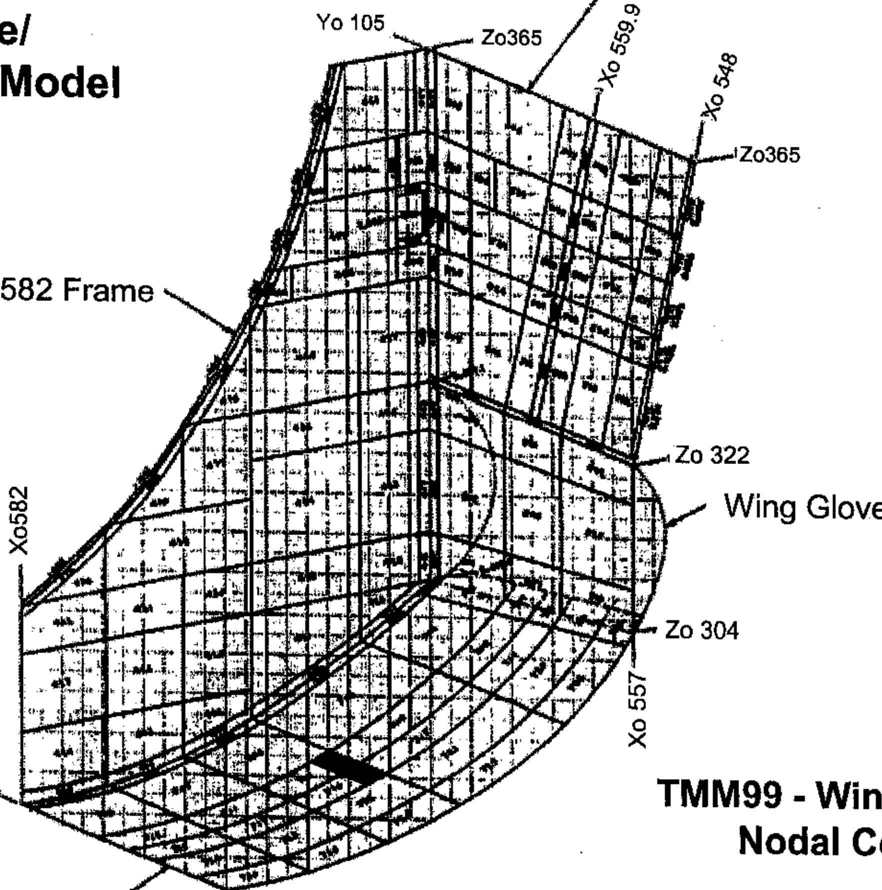
- OI Structural Temperature Data Indicated Nominal Temperatures
- Tempilabels Inside the Wing Area Indicated Nominal Temperature
- No Evidence of Structural Damage Under Removed Tiles Was Observed

Location	Tile Damage	Surface Temp	Structure Temp	Comments
TMM 99	Limited Fusing	3100°	276°	No Impact
TMM 352	Limited Fusing	2800°	309°	No Impact

OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998

**Detailed Wing Glove/
Chine Certification Model
Used in Evaluation**

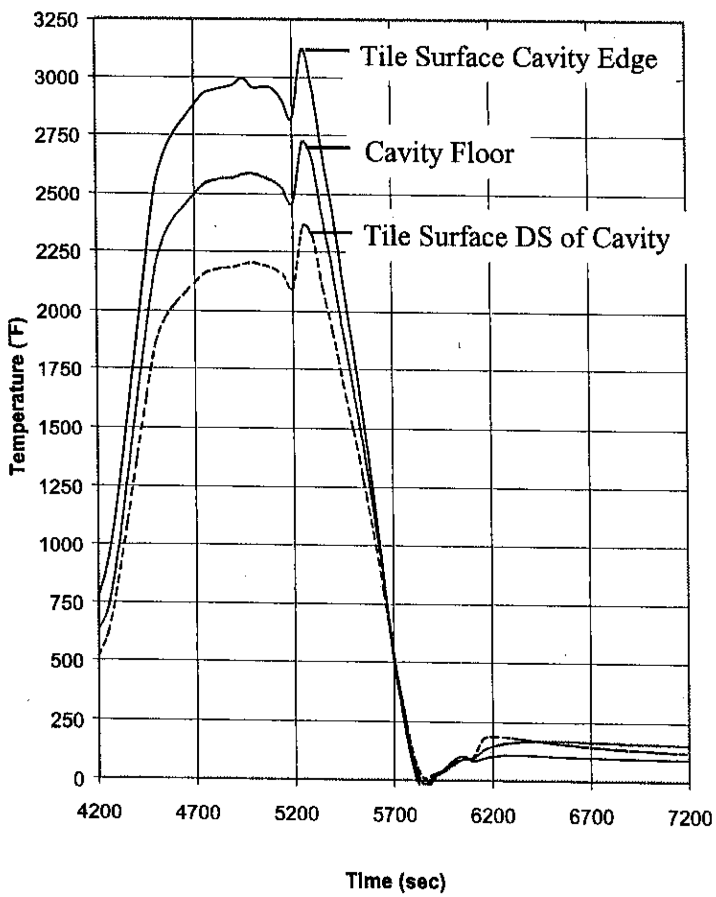


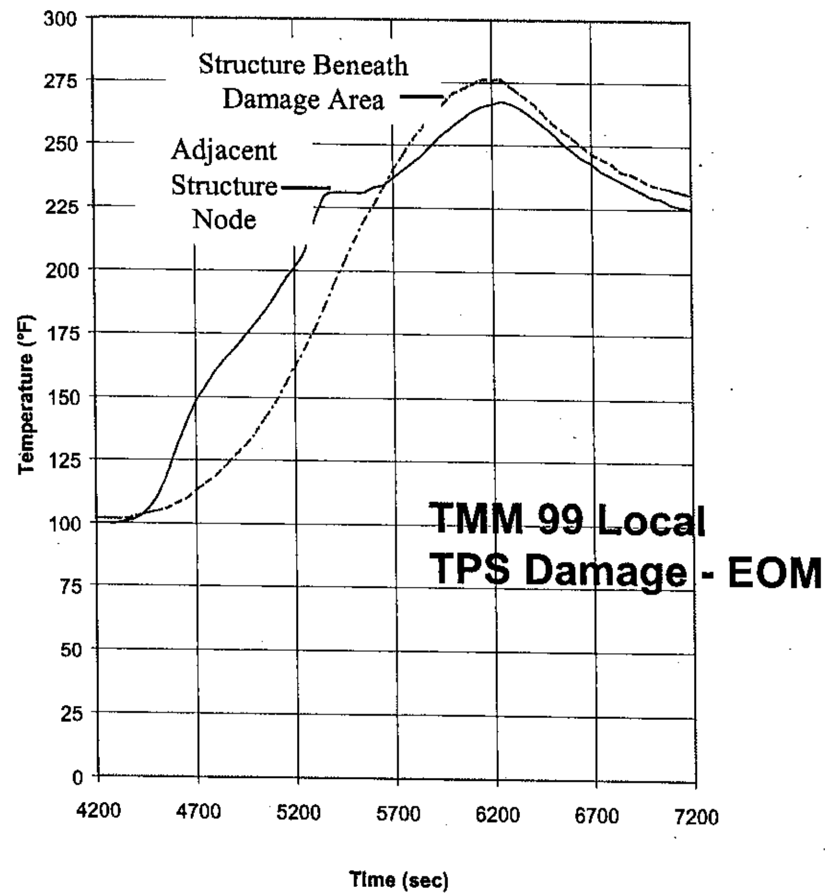
**TMM99 - Wing Glove at X_o582
Nodal Configuration**

OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998

Temperatures Indicate TPS Surface Damage; Structure Okay



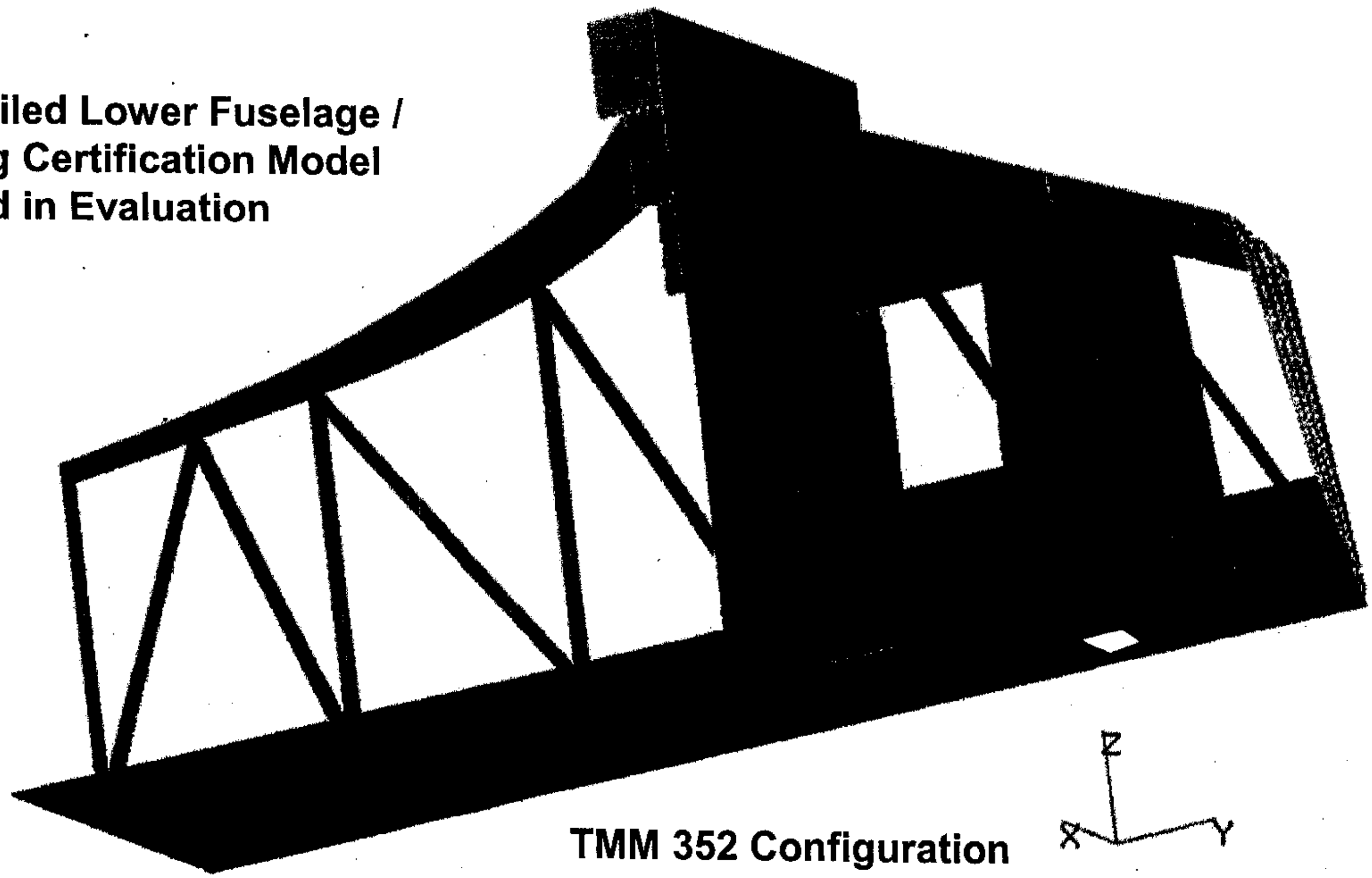


OV-102 (STS-87) TPS Damage

Presenter
R. Gatto

Date
January 6, 1998

Detailed Lower Fuselage / Wing Certification Model Used in Evaluation



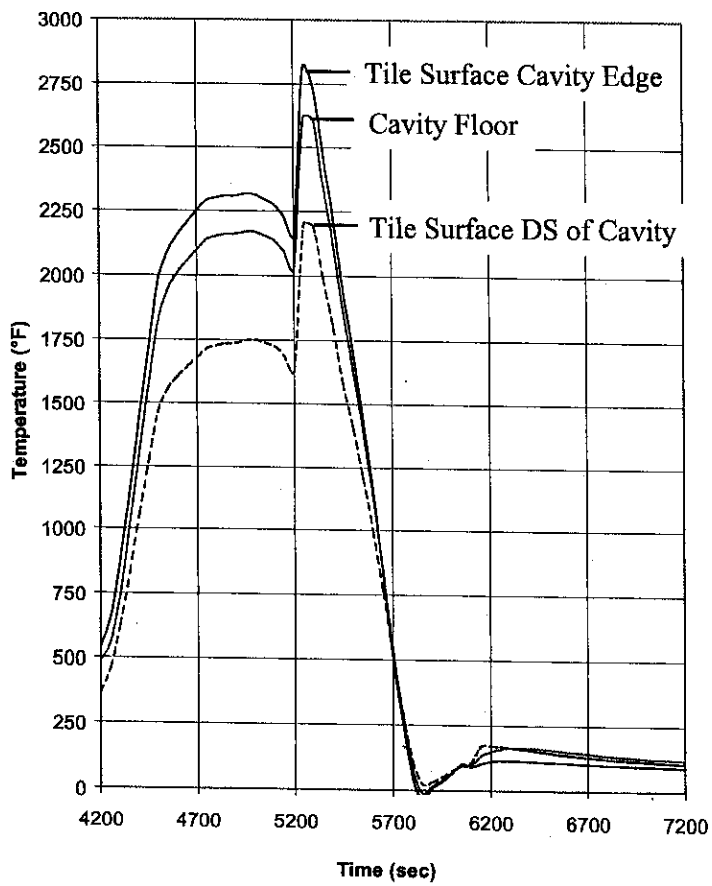
TMM 352 Configuration

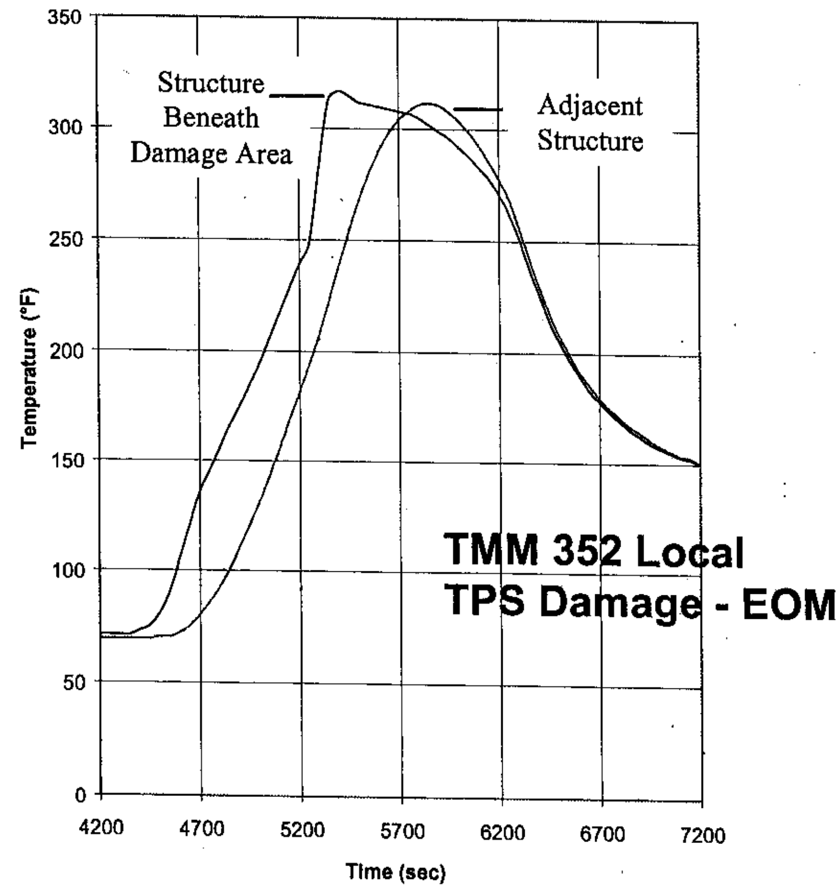
OV-102 (STS-87) TPS Damage

Presenter
R. Gatto

Date
January 6, 1998

Local TPS Surface Damage Expected; Structure Acceptable





OV-102 (STS-87) TPS Damage

Presenter
R. Gatto
Date
January 6, 1998

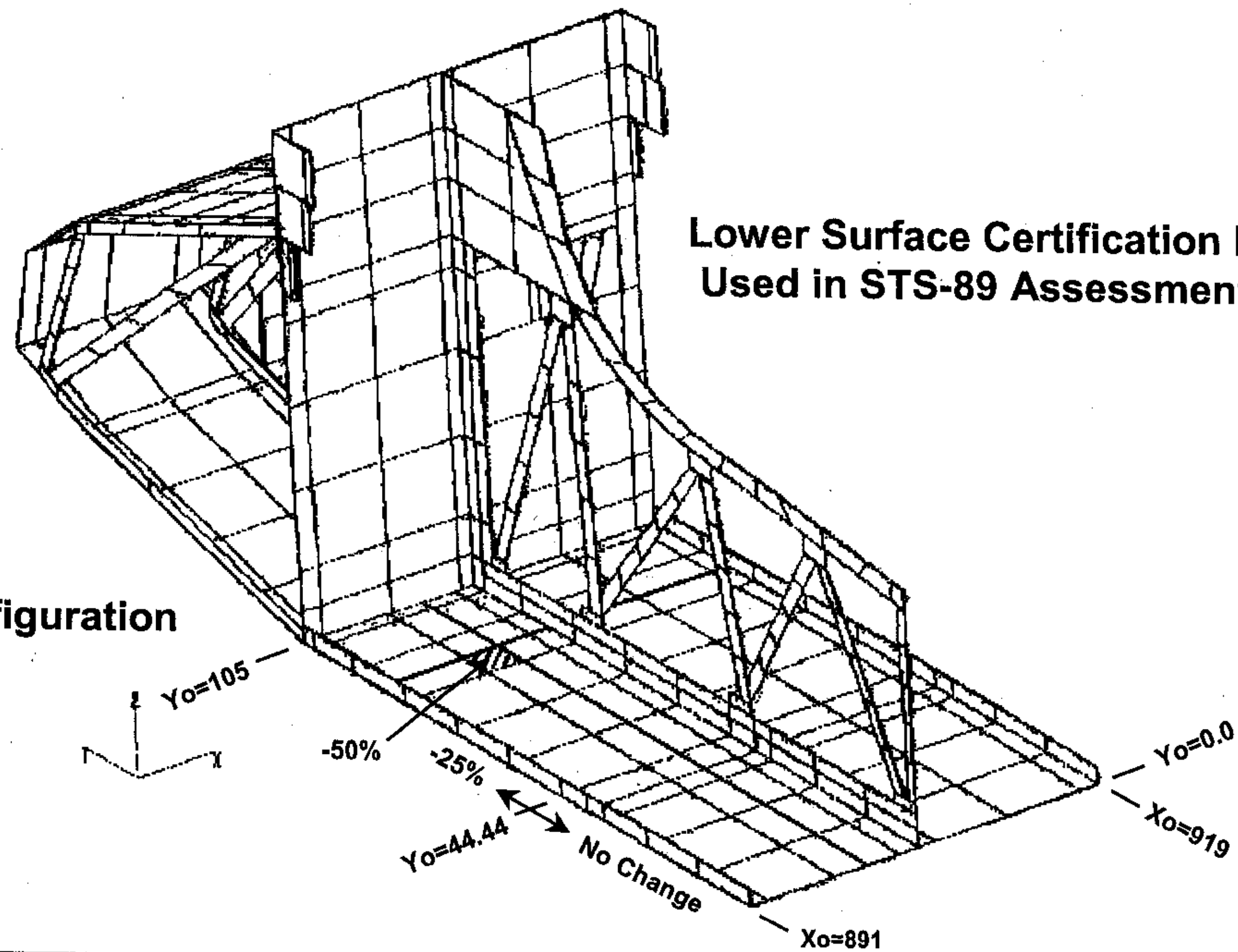
Results of STS-89 Evaluation:

- Local TPS and Structural Temperature Similar to STS-87 Experience if Damage is Similar
  - Debris Strike Producing Tile Loss to Densified Layer Could Cause Structural Thermal Damage

	Location	Tile Damage	Surface Temp °F	Structure Temp °F	Comments
EOM	TMM 99	Limited Melting	3100	272	No Issue
	TMM 352 • 50% Loss • Loss to Densified	Tile Surface Melting	2850 3150	330 506	No Issue Debond H/C
	TMM 353	Minimal	2420	366	Margin Issue
TAL	TMM 99	Tile Melting Burrowing	3300	195	No Issue
	TMM352 Densified	Minimal	2850	425	Local Structure Damage

OV-102 (STS-87) TPS Damage

Presenter: R. Gatto
Date: January 6, 1998



Lower Surface Certification Model
Used in STS-89 Assessment

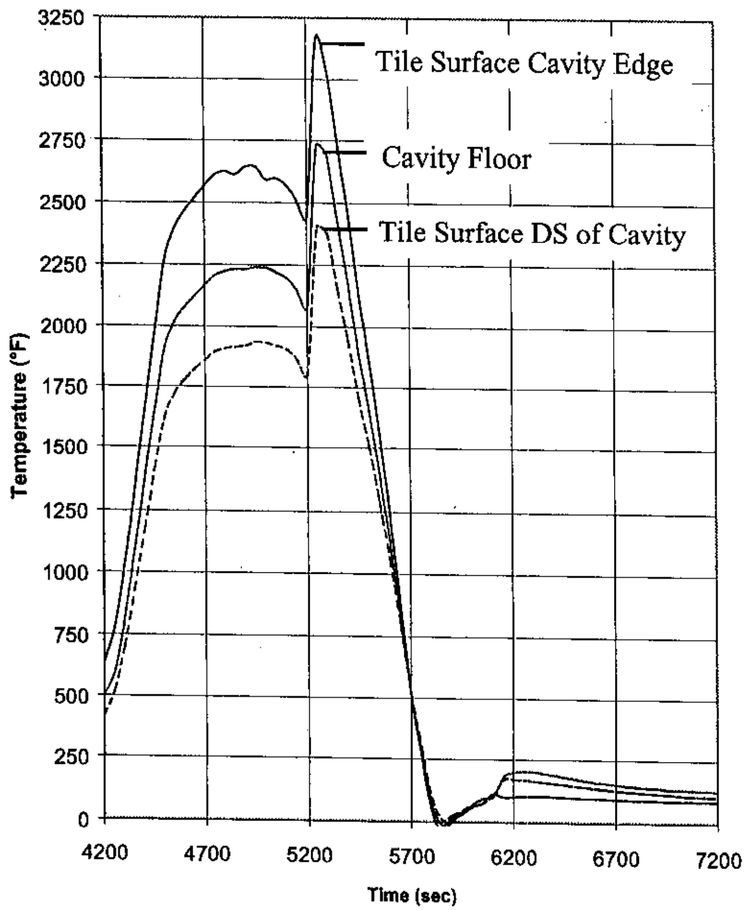
TMM 353 Configuration

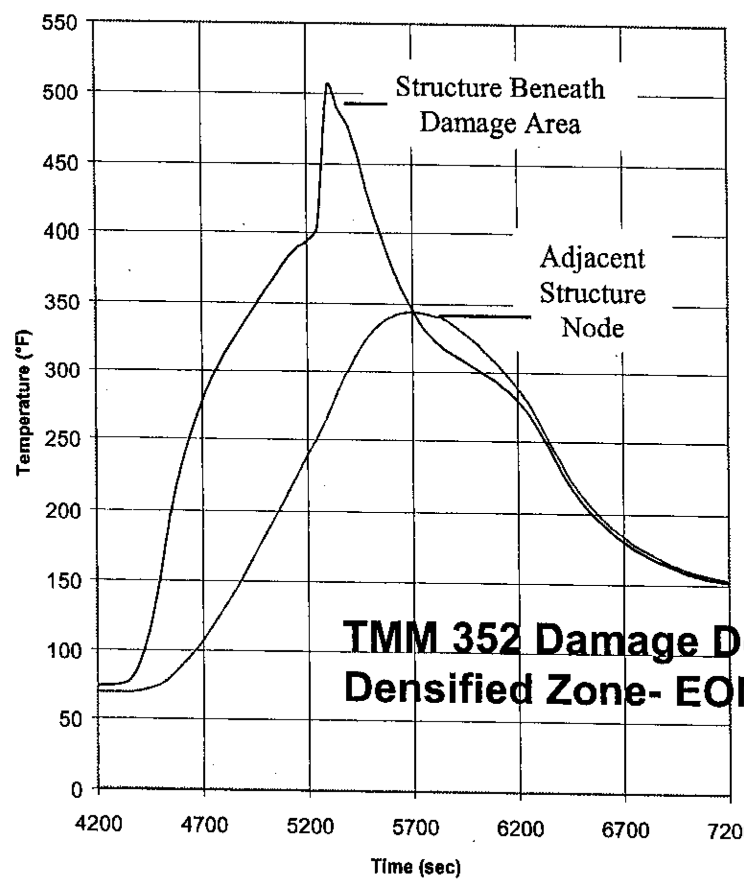
OV-102 (STS-87) TPS Damage

Presenter
R. Gatto

Date
January 6, 1998

Tile Damage to Densified Zone Produces Structural Damage





TMM 352 Damage Down to Densified Zone- EOM

BOEING

Boeing North American, Inc.
Reusable Space Systems

Information, Space & Defense Group
12214 Lakewood Boulevard
Downey, CA 90242-2693

Date: April 2, 1998

No.: 270-200-98-017

To: J. T. Hughes
RSS - Downey
D/270-200, 841-AC85

From: M. L. Helsel, V. H. Bui
RSS - Downey
D/270-200, 841-AC85

Subject: **TPS Damage Assessment of STS-87 and STS-89**

The purpose of this letter is to document the work performed to assess the damage to the TPS of OV-102 during STS-87 and the potential damage to the TPS of OV-105 during the next flight, STS-89.

Summary:
Analysis performed on the existing condition of the OV-102 lower surface tile following STS-87 showed that there were no structural temperatures or temperature gradients which exceeded material limits. Similar tile damage was simulated on OV-105 at various locations within the potential debris path. Analysis showed local structural damage could result if the damage were to occur at thin tile locations. This situation would lead to safe vehicle return, but with local structural repairs recquired. Simulation of more severe damage on OV-105 than was experienced during STS-87, indicated minimal tile damage, but significant increases in temperature gradients recquied analysis by the Stress group for safety margin violations.

Observation and Concern:
An unusual number of damaged tiles was observed on OV-102 after STS-87. Two concerns arose from this observation: potential temperature or margins violations on OV-102, and the potential of similar TPS damage on OV-105 during the next flight, STS-89.

Discussion:
OV-102 TPS sustained a total of 308 hits during STS-87. The lower surface had 244 hits with 109 hits greater than 1 inch in length. The major damage area on the lower surface was between the nose landing gear door and the main landing gear doors. The longest damage was located on the wing glove and measured 15"x2"x0.25", and the deepest damage was located forward of the left main landing gear door and measured 4"x2"x1.5".

The purpose of this analysis was to evaluate the TPS and structure on OV-102 in the worst damage areas during STS-87, and predict temperatures of these areas on OV-105 if STS-89 were to experience the same damage and potentially worse damage.

STS-87 Thermal Analysis:

To analyze the temperatures experienced by the OV-102 lower surface TPS, mission specific aeroheating was generated for EOM, and existing thermal math models (TMMs) were selected which covered the two worst damage areas. (SeFigure 1). TMM 99, located on the lower wing glove, was chosen to simulate one of the longer damage sites, and TMM 352, located near the left main landing gear door, was chosen to cover the site of the deepest damage.

TMM 99

The impact damage analyzed in the area of TMM 99 was 6"x1"x0.75". This is one of the longer damages with significant depth (the 15" long damage was only 0.25" in depth.) The certification model 99 was modified to include a cavity 6.81"x1"x0.86" in the center of the homogeneous 3-D model. (The size difference was for convenience due to the existing node dimensions in the model.)

The tile was renodalized in the area around the hole. Refined elements on the downstream side of the hole were created to help simulate the cavity heating effects. Elements beneath the cavity were also refined.

To simulate the increased local heating due to the presence of the cavity, bump factors, provided by aeroheating, were imposed on the heating in and around the holFigure 3 shows the heating factors and where they were applied. The emissivity of the damaged tile surfaces was reduced to 0.5 due to the lack of black coating. Bottom sun entry interface (EI) temperatures were used for a worst case analysis.

TMM 352

TMM 352 is a large model covering the area of the lower fuselage and wing around the left main landing gear door (MLGD.) The deepest of the damage sites was analyzed using this model. Because the damage was so deep in this area and the fact that it did not penetrate to the aluminum structure dictated that the tile in the area of impact was more than 1.5" thick. The hole was placed over the frame next to the MLGD because the tile in this region is thick enough to accommodate such a deep hole. This cavity has dimensions 4"x4"x1.5".

The model was renodalized in a similar manner to the TMM 99 modification. Heating bump factors were generated for this configuration as shown Figure 5. The 0.5 emissivity for broken tile and the bottom sun EI temperatures were also used for this analysis.

STS-89 Thermal Analysis:

The impact of potential damage on flight 89 was evaluated with two scenarios. The first was the same local damage as occurred on STS-87, and the second evaluated the potential reduction of safety margins if the STS-89 tile damage was more severe than the STS-87 experience. The local damage scenario was analyzed similar to the STS-87 analysis using TMMs 99 and 352. The more severe damage scenario was evaluated using wing/fuselage model TMM 353. Mission specific aeroheating was generated for EOM and TAL for STS-89. The 0.5 emissivity for broken tile and the bottom sun EI temperatures were used for all analyses.

TMM 99

The evaluation of STS-89 on TMM 99 utilized the same hole configuration and bump heating factors as that of STS-87. Both EOM and TAL trajectories were analyzed.

TMM 352

The location of the damage analyzed on OV-102 has a large frame attached to the underlying aluminum skin. This large mass distributed the heat well. However, there was no guarantee that damage would occur again at this benign location, and analysis of potential damage in this location would be unconservative. Therefore, a second hole location was chosen forward of the MLGD and away from the frame. The tile in this region is 1.15 inches. Two depths of this hole location were analyzed: one 4"x4"x0.5" (50% tile loss), and the other 4"x4"x1", leaving only the 0.15" densified layer of the tile. Heating factors were calculated for these two configurations (Figure 6), and both models were analyzed for the EOM and TAL trajectories.

TMM 353

Structural analysis identified temperature gradients at the bottom panel from the centerline to the side wall of the mid-fuselage bottom at Xo1050 as a critical margin area. TMM 353 was chosen to simulate extensive damage in this area. The analysis considered a 25% tile loss over one frame bay of the bottom. Within this area, one tile was reduced to 50% thickness. See Figure 7.

Analysis Results:

The results of the evaluations are presented in Table 1 and Figure 8 through Figure 20. The STS-87 analysis resulted in TPS surface temperatures at the damage sites just above the melting point of the material. The local structure temperature results were all below material limits.

The STS-89 evaluation of potential local damage showed that if OV-105 were to experience damage identical to that of OV-102 during STS-87, the results would be similar; over heating of tile material with structural temperatures within certification limits. However, the results of the TMM 352 analysis of hole location 2, the thinner tile, show that the structure would exceed the 350° F material limit, and debonding of the honeycomb structure in that area would be expected. Therefore, if the deep damage which occurred on the thicker tiles in the area of TMM 352 were to occur a few inches inboard, where the tiles and the structure are thinner, local structural damage would occur. The adjacent structure would be able to pick up the load with no safety of flight issue but possible structural damage.

Evaluation of extensive damage on the outboard lower surface using TMM 353 indicated minimal tile damage. However, the structural temperatures and temperature gradients exceeded acceptable limits. The temperature results of this analysis were assessed by the structures group and their conclusion was that large in-plane gradients and thermal stresses result in unacceptable margins of safety.

Conclusions:

Damage to OV-102 during STS-87 was limited to the TPS. There were no local temperatures exceeding structural temperature limits, and no safety margins were violated. STS-87 severity of impacts on OV-105 during STS-89 would have safe vehicle return but with the possibility of local structural damage.

Potential STS-89 damage more severe than that on experienced on STS-87 could significantly degrade safety margins. The wider area of impact damage assessed on the bottom panels resulted in unacceptable margins.

M. L. Helsel

M. L. Helsel
Member of Technical Staff
Vehicle and Systems Analysis

Vanessa Bui

V. H. Bui
Member of Technical Staff
Vehicle and Systems Analysis

cc:
H. Sharifzadeh___ AC85
A. Mirdamadi AB15

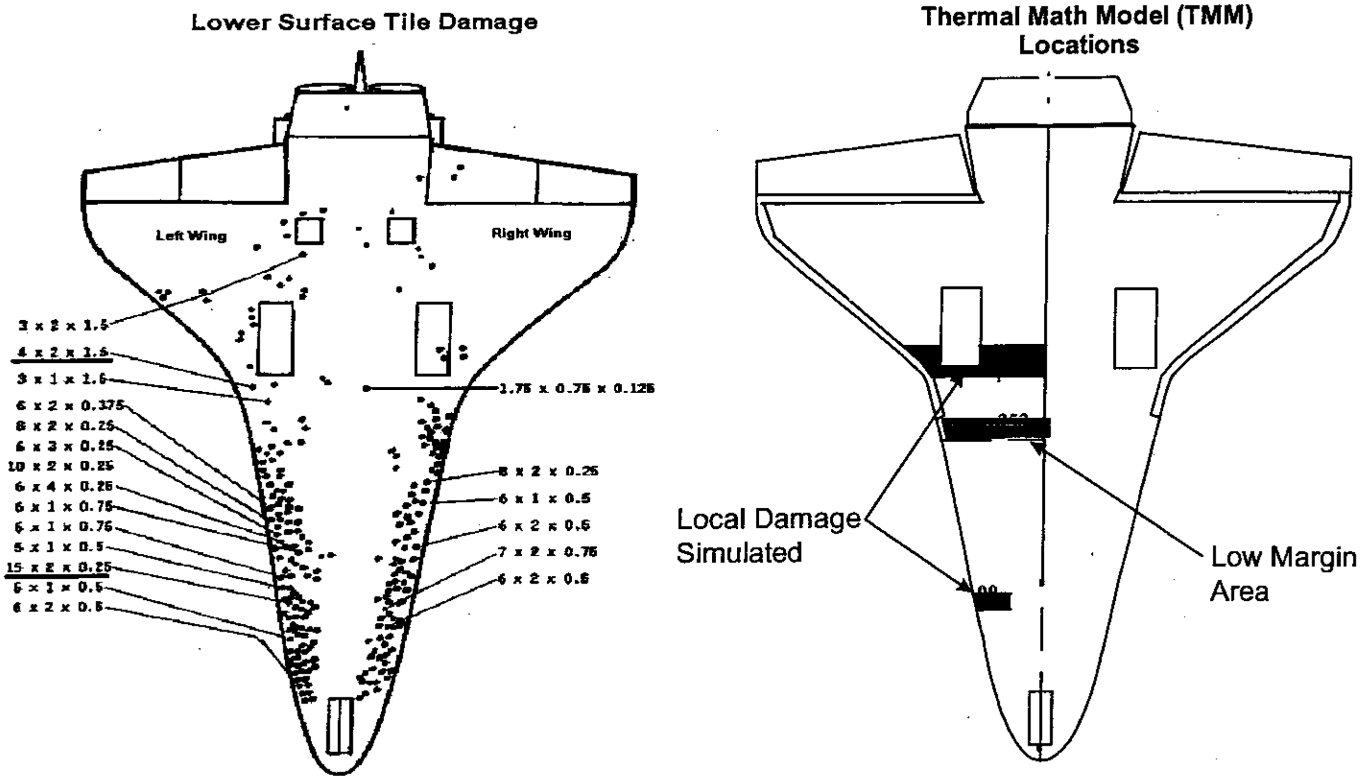


Figure 1 - Model Locations Chosen to Analyze Worst Damage Sites

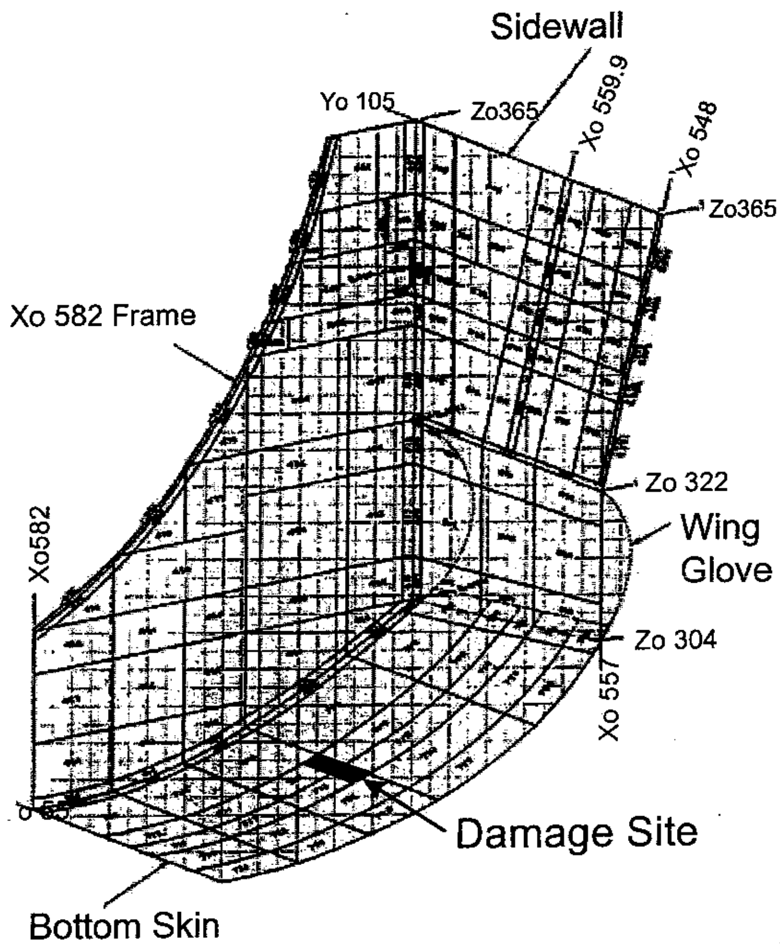


Figure 2 - Nodal Diagram of TMM 99 Structure

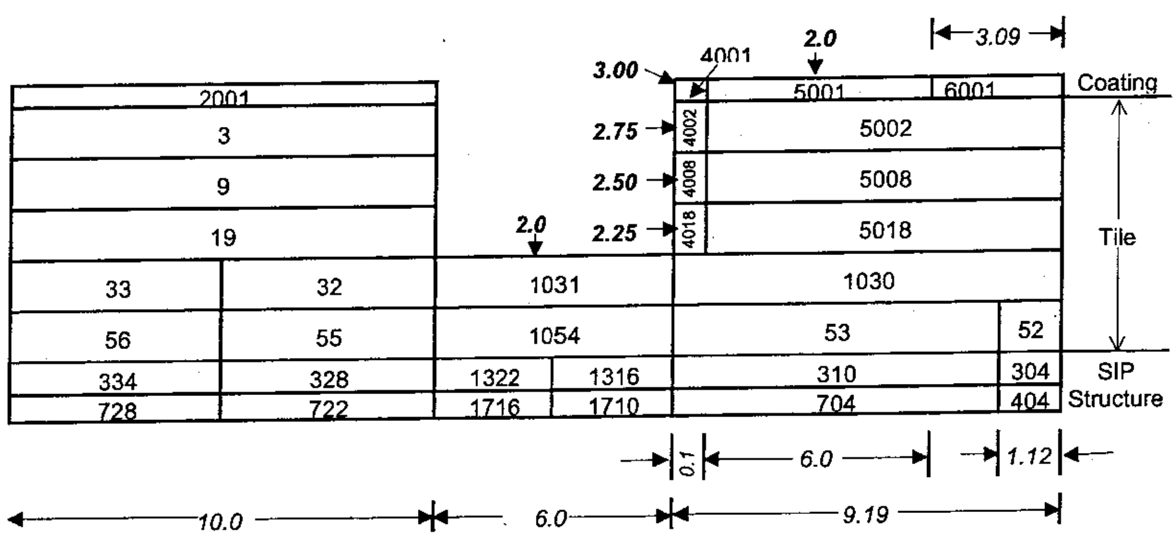


Figure 3 - Cross Section Nodal Diagram of TMM 99
(Heating Bump Factors in Bold Face Type)

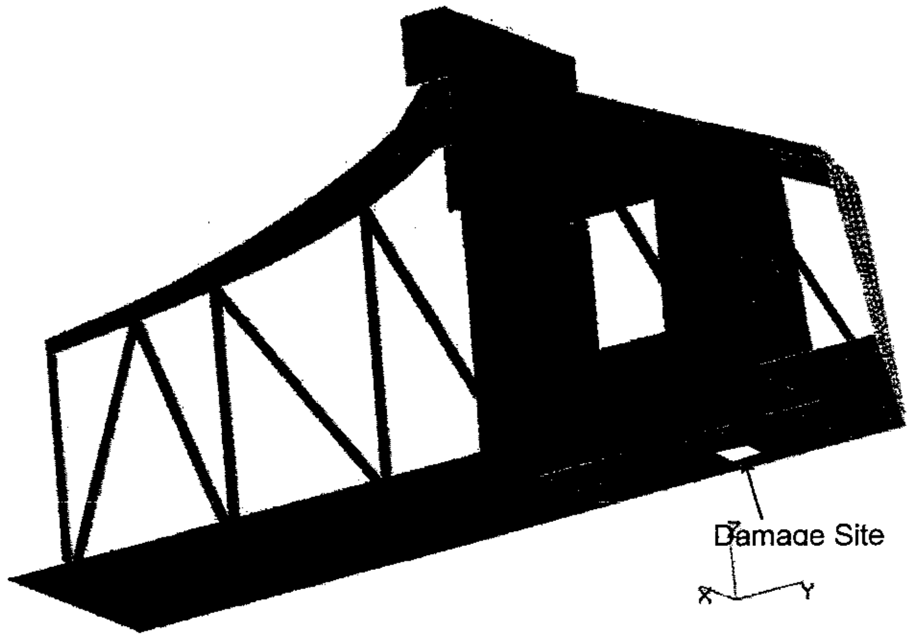


Figure 4 - TMM 352 Structure

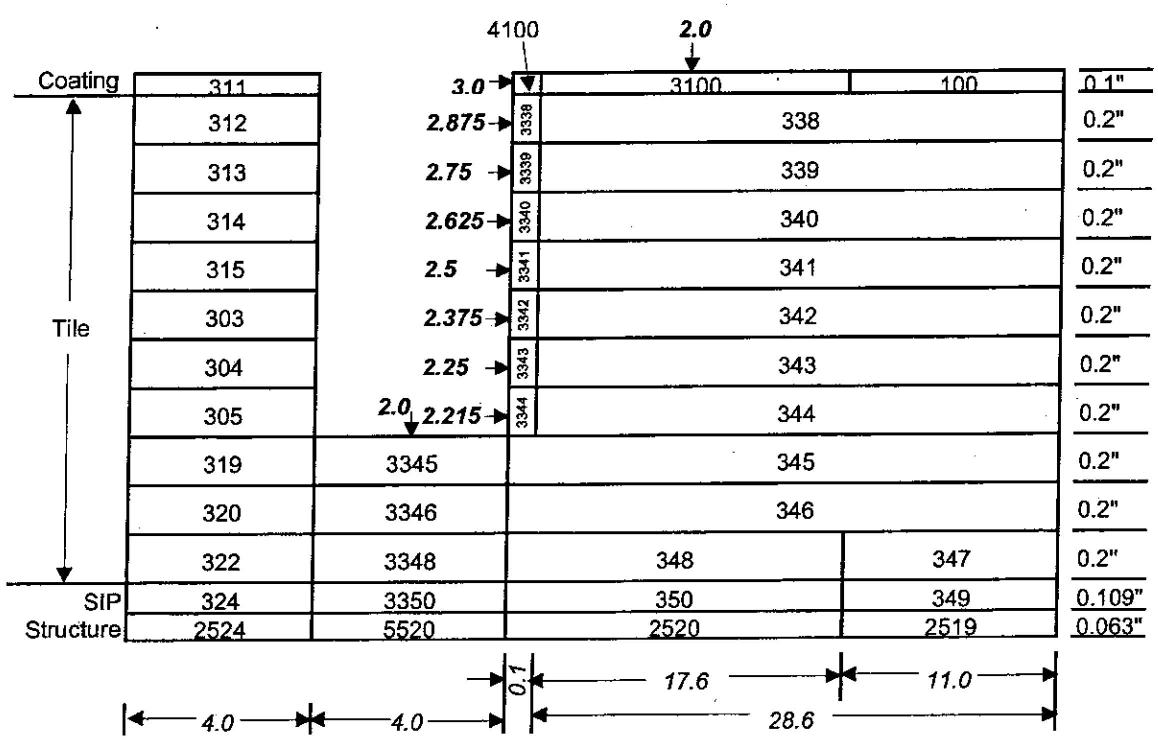
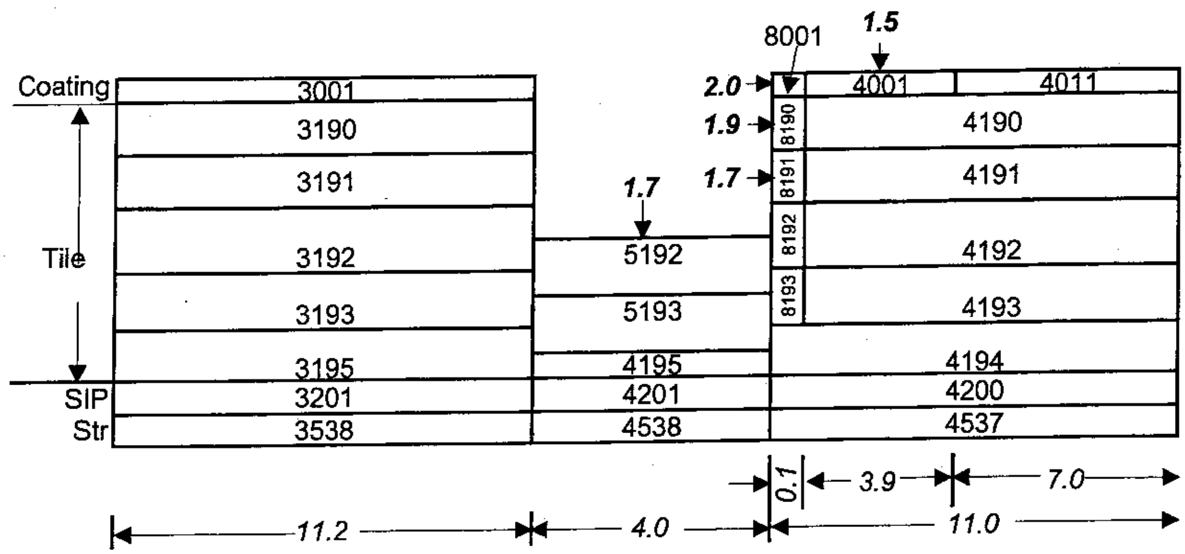
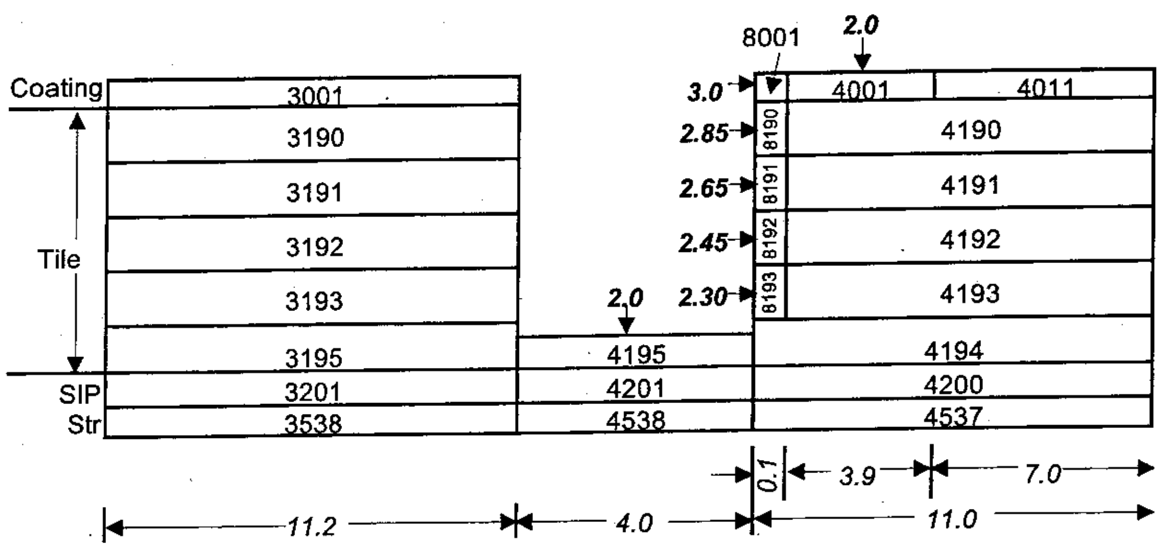


Figure 5 - Cross Section Nodal Diagram of Hole Location 1 of TMM 352 (Heating Bump Factors in Bold Face Type)



(a) 50% Tile Loss



(b) Loss to Densified Layer

**Figure 6 - Cross Section Nodal Diagram of Hole Location 2 of TMM 352
(Heating Bump Factors in Bold Face Type)**

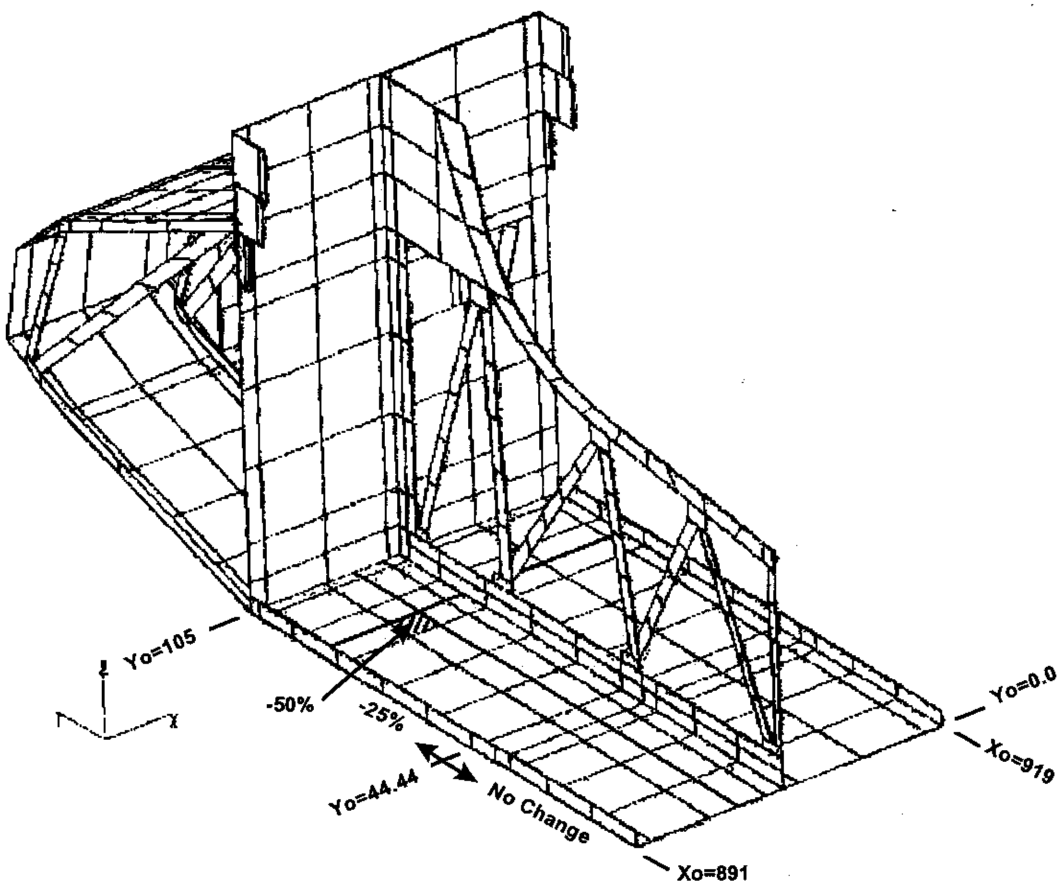


Figure 7 - Simulated Damage Location on TMM 353

Table 1 - Maximum Surface and Structure Temperatures for STS-87 Analysis

			Maximum Temperatures (°F)					
			STS-87 EOM		**STS-89 EOM**		**STS-89 TAL**	
Model	Cavity Size	Damage Description	Surface	Structure	Surface	Structure	Surface	Structure
TMM 99	6.8"x1"x0.86"	STS-87 Damage	2940	293	2988	293	3500	211
TMM 352 2.2" Tile	4"x4"x1.5"	STS-87 Damage	2878	123/280*	3109	109/125*	3363	245/287*
1.15" Tile	4"x4"x0.5"	50% Tile Loss	2621	309	2315	317	-	-
1.15" Tile	4"x4"x1.0"	Loss to Densified	2927	485	3162	505	3040	435

* Structure node beneath cavity / Hottest structure node

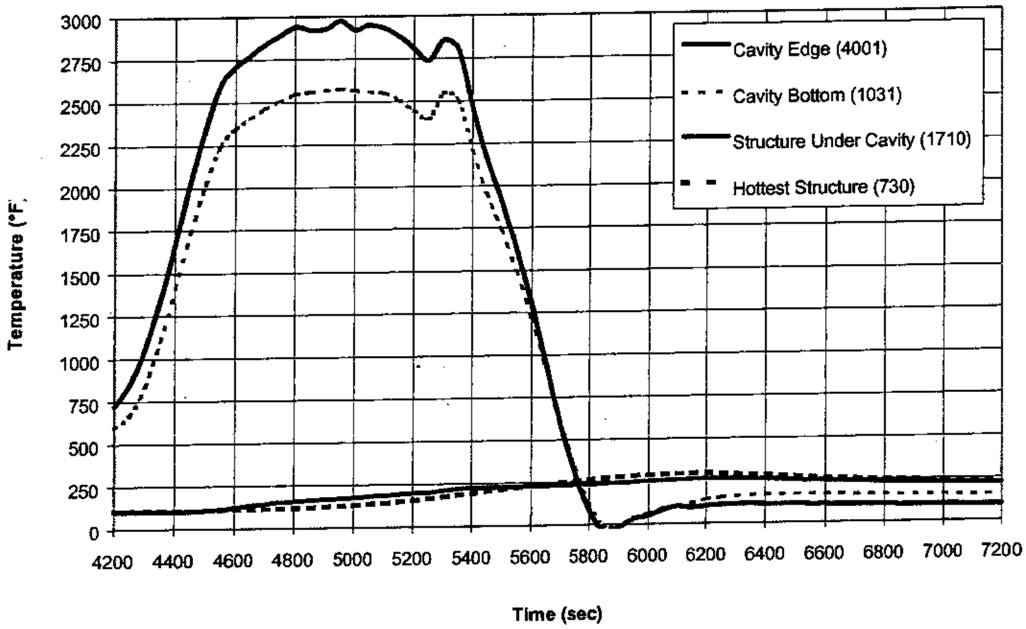


Figure 8 - STS-87 Temperature Results for TMM 99

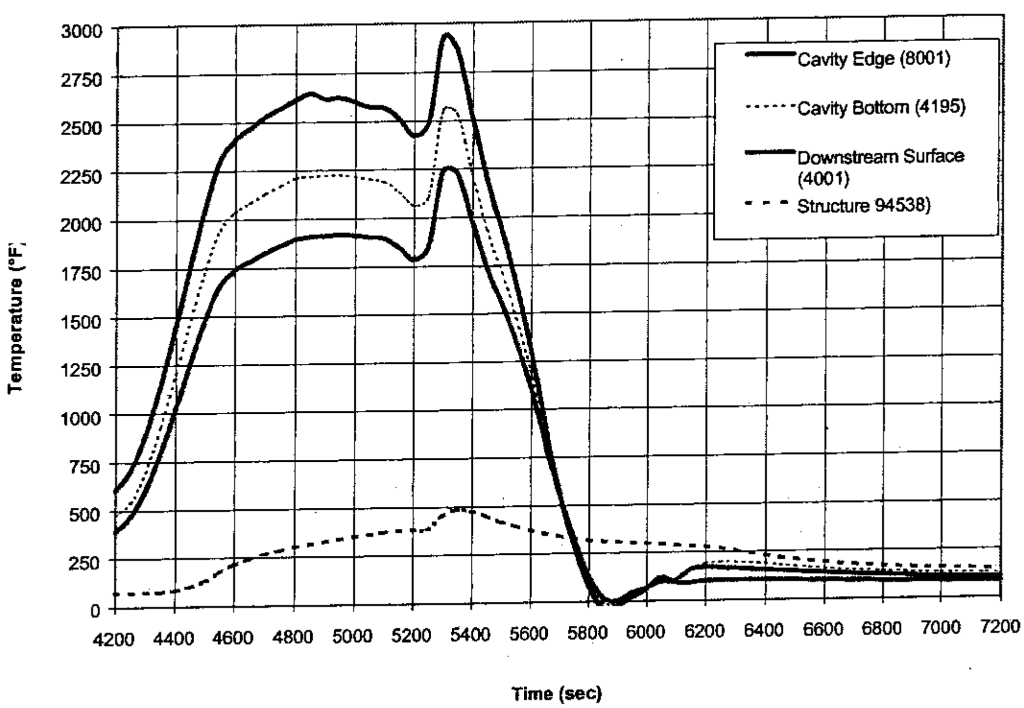


Figure 9 - STS-87 Temperature Results for TMM 352 Hole Location 1

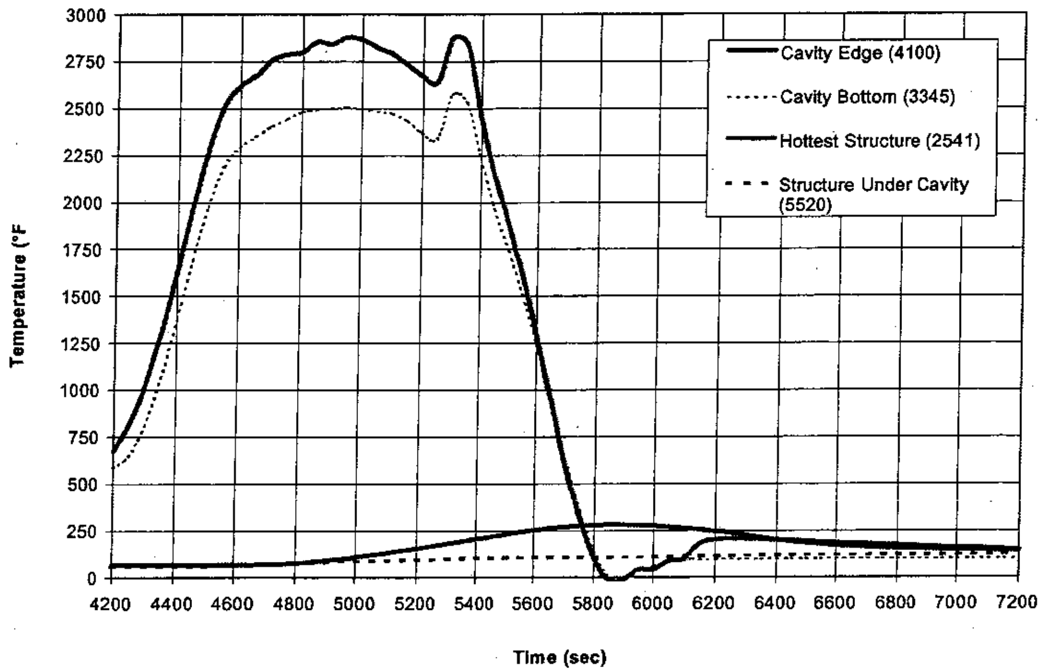


Figure 10 - STS-87 Temperature Results for TMM 352 Hole Location 2 (50% Tile Loss)

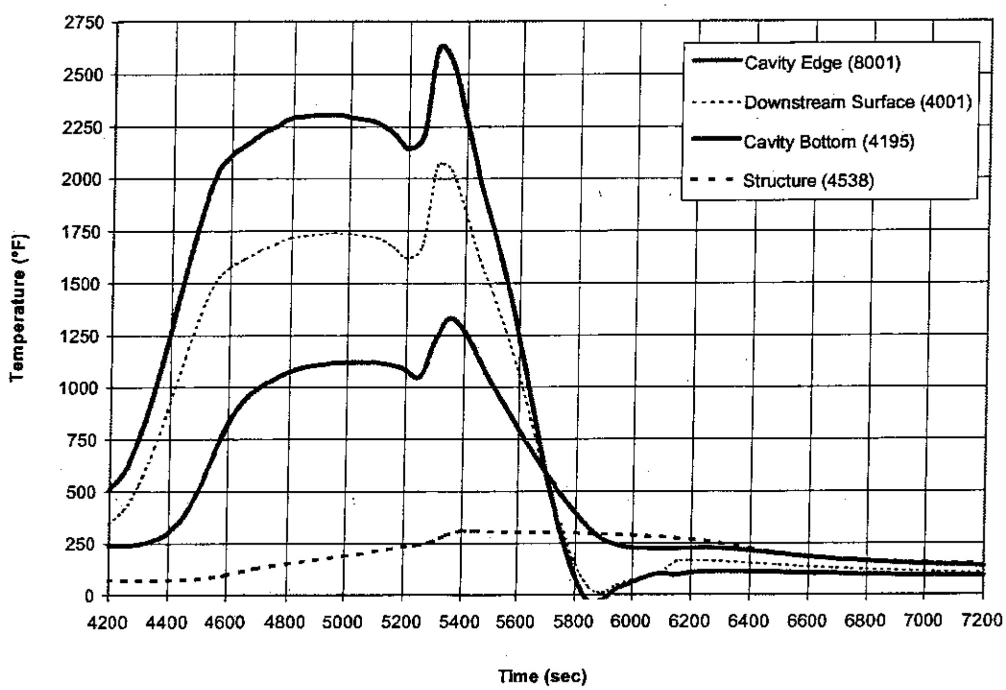


Figure 11 - STS-87 Temperature Results for TMM 352 Hole Location 2 (Loss to Densified Layer)

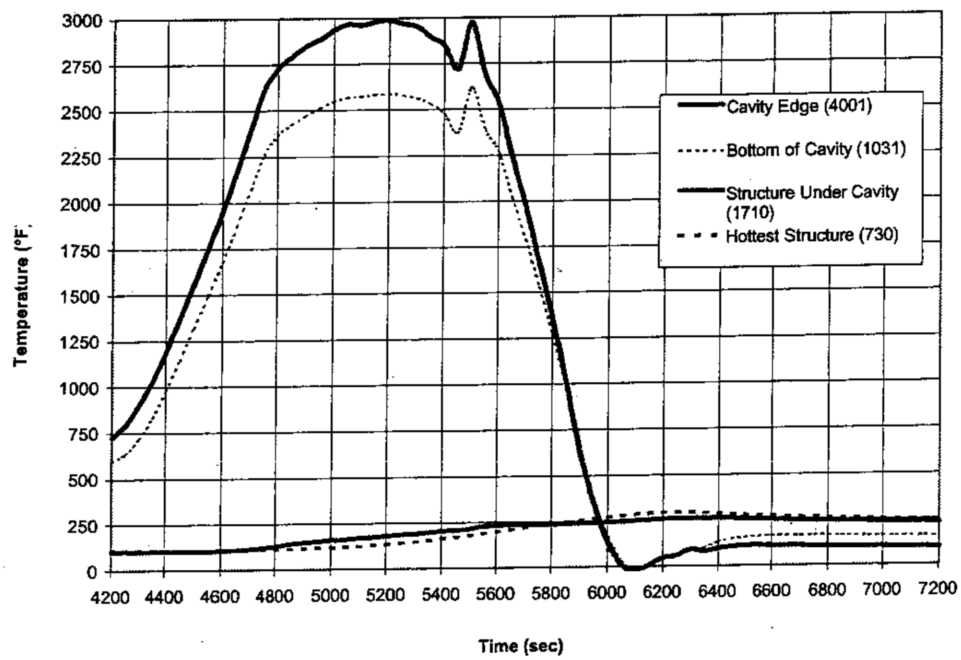


Figure 12 - STS-89 EOM Temperature Results for TMM 99

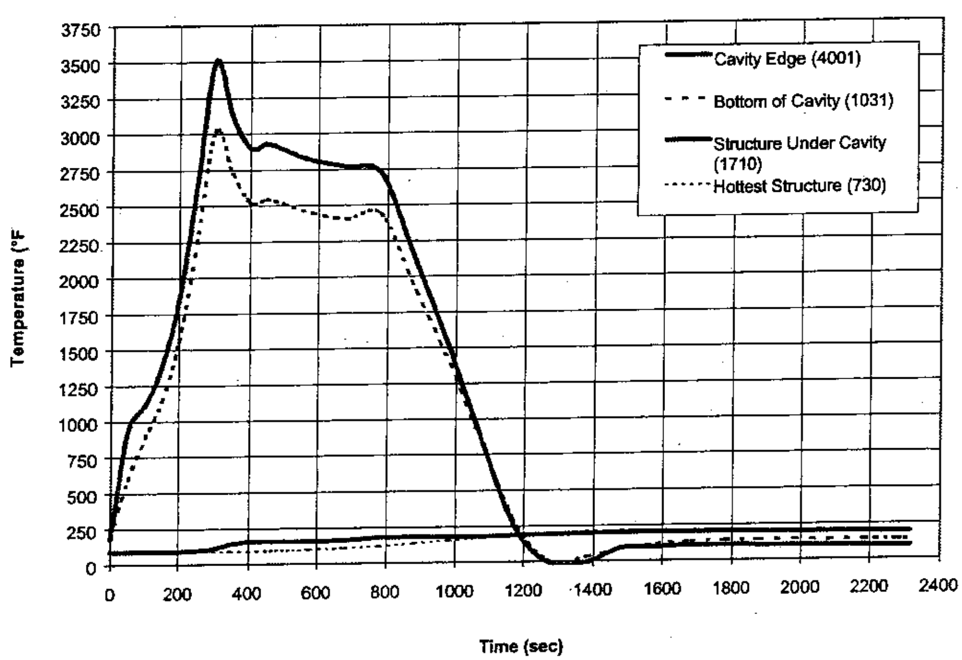


Figure 13 - STS-89 TAL Temperature Results for TMM 99

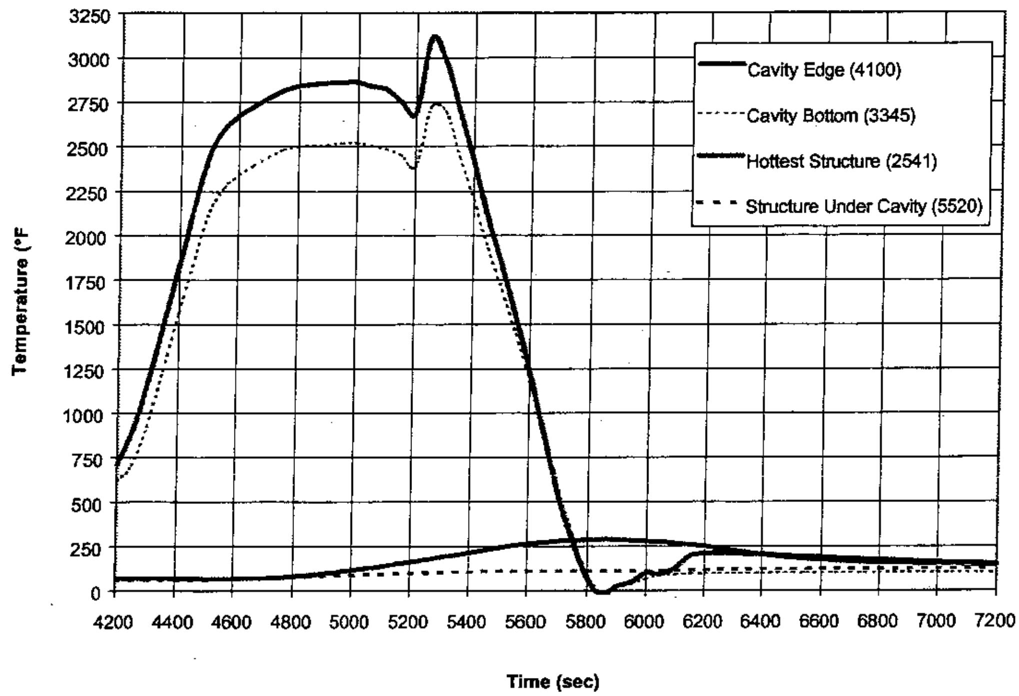


Figure 14 - STS-89 EOM Temperature Results for TMM 352 Hole Location 1

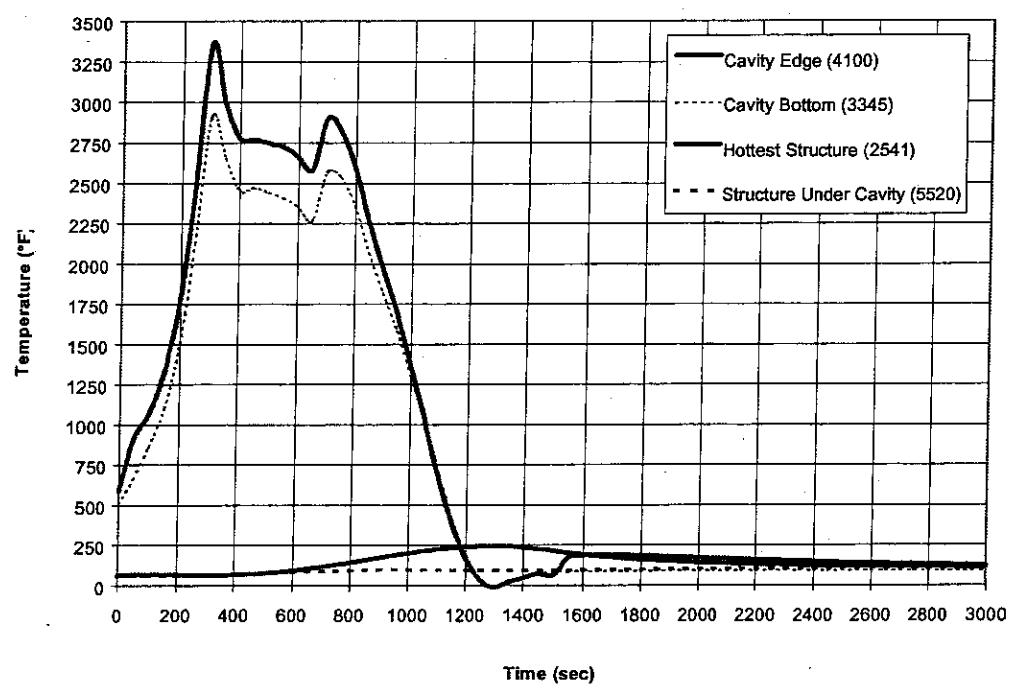


Figure 15 - STS-89 TAL Temperature Results for TMM 352 Hole Location 1

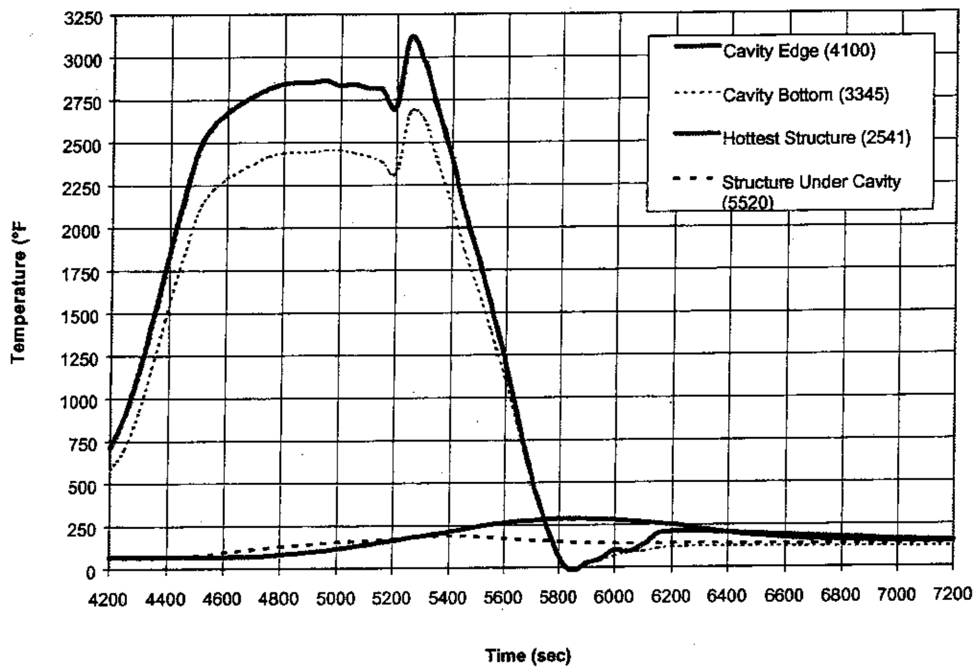


Figure 16 - STS-89 EOM Temperature Results for TMM 352 Hole Location 1 (Loss to Densified Layer)

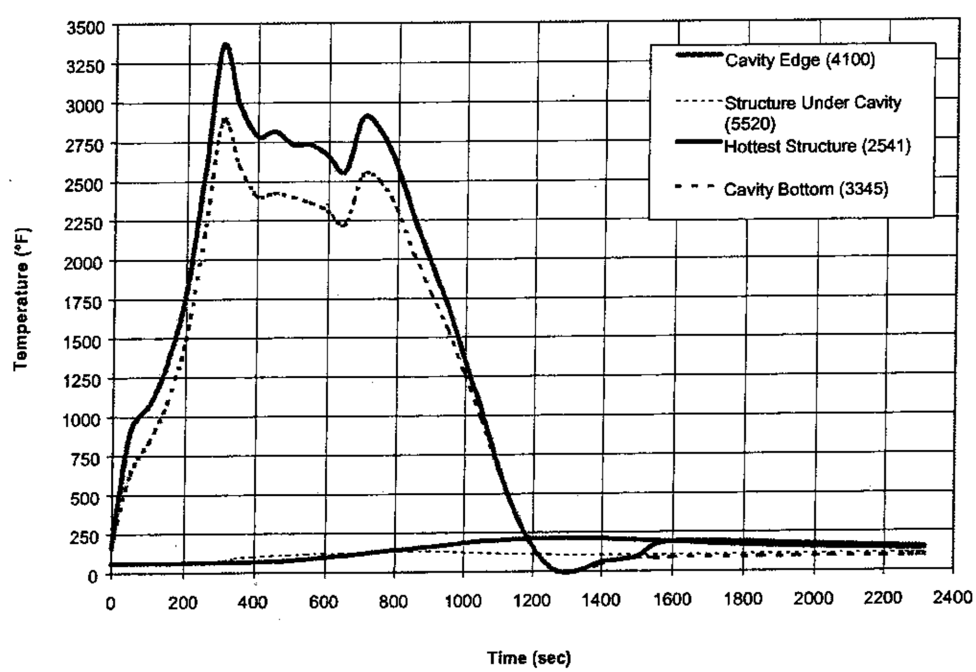


Figure 17 - STS-89 TAL Temperature Results for TMM 352 Hole Location 1 (Loss to Densified Layer)

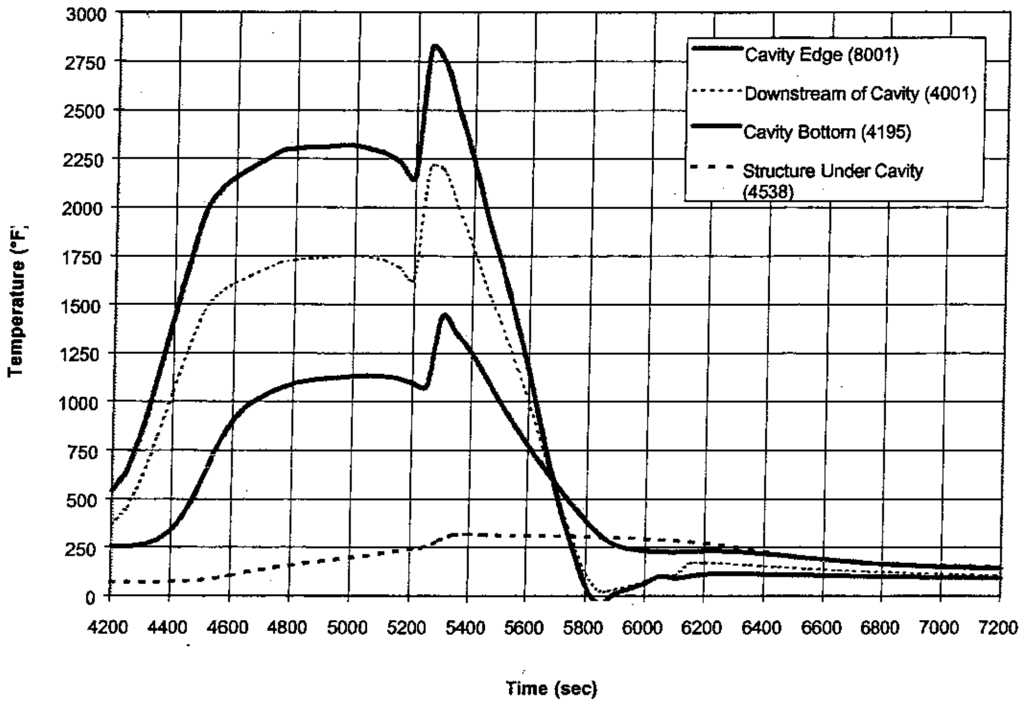


Figure 18 - STS-89 EOM Temperature Results for TMM 352 Hole Location 2 (50% Tile Loss)

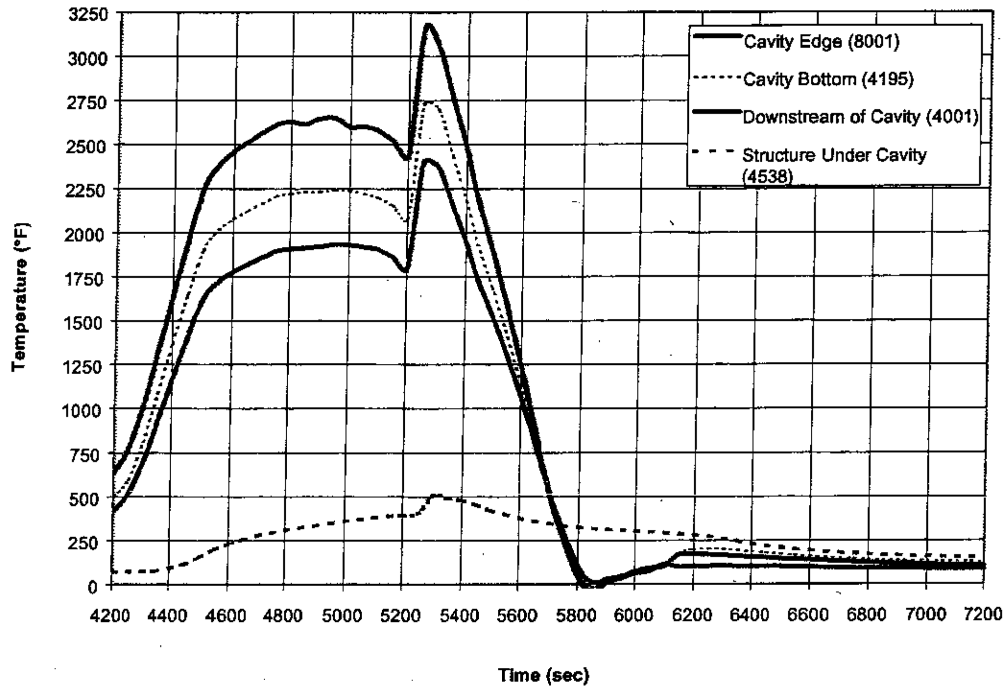


Figure 19 - STS-89 EOM Temperature Results for TMM 352 Hole Location 2 (Loss to Densified Layer)

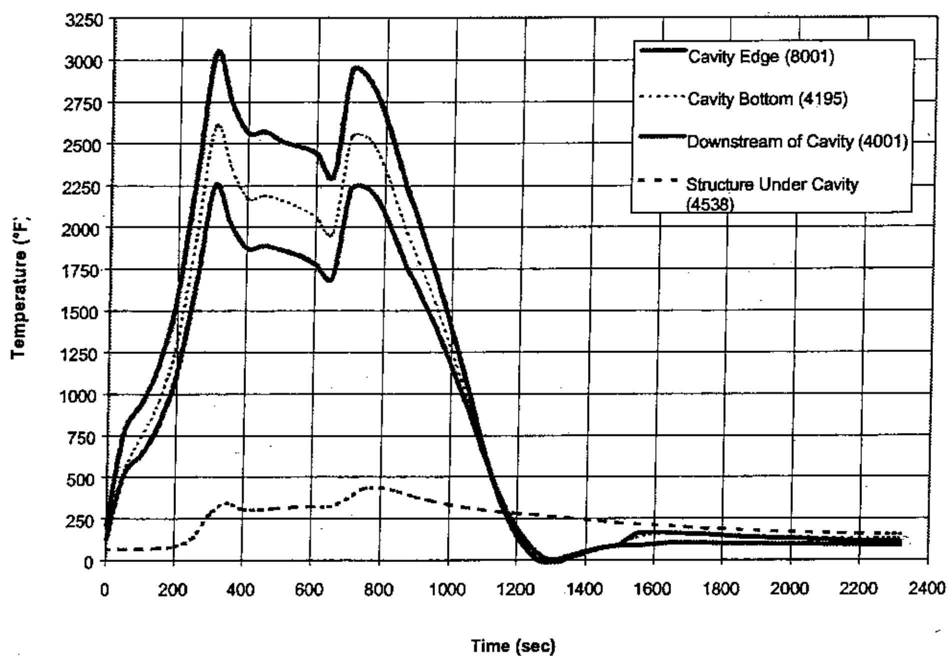


Figure 20 - STS-89 TAL Temperature Results for TMM 352 Hole Location 2 (Loss to Densified Layer)

BOEING

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Date: April 2, 1998

No.: 270-200-98-017

To: J. T. Hughes
RSS - Downey
D/270-200, 841-AC85

From: M. L. Helsel, V. H. Bui
RSS - Downey
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Subject: **TPS Damage Assessment of STS-87 and STS-89**

The purpose of this letter is to document the work performed to assess the damage to the TPS of OV-102 during STS-87 and the potential damage to the TPS of OV-105 during the next flight, STS-89.

Summary:

Analysis performed on the existing condition of the OV-102 lower surface tile following STS-87 showed that there were no structural temperatures or temperature gradients which exceeded material limits. Similar tile damage was simulated on OV-105 at various locations within the potential debris path. Analysis showed local structural damage could result if the damage were to occur at thin tile locations. This situation would lead to safe vehicle return, but with local structural repairs recquired. Simulation of more severe damage on OV-105 than was experienced during STS-87, indicated minimal tile damage, but significant increases in temperature gradients recquied analysis by the Stress group for safety margin violations.

Observation and Concern:

An unusual number of damaged tiles was observed on OV-102 after STS-87. Two concerns arose from this observation: potential temperature or margins violations on OV-102, and the potential of similar TPS damage on OV-105 during the next flight, STS-89.

Discussion:

OV-102 TPS sustained a total of 308 hits during STS-87. The lower surface had 244 hits with 109 hits greater than 1 inch in length. The major damage area on the lower surface was between the nose landing gear door and the main landing gear doors. The longest damage was located on the wing glove and measured 15"x2"x0.25", and the deepest damage was located forward of the left main landing gear door and measured 4"x2"x1.5".

The purpose of this analysis was to evaluate the TPS and structure on OV-102 in the worst damage areas during STS-87, and predict temperatures of these areas on OV-105 if STS-89 were to experience the same damage and potentially worse damage.

STS-87 Thermal Analysis:

To analyze the temperatures experienced by the OV-102 lower surface TPS, mission specific aeroheating was generated for EOM, and existing thermal math models (TMMs) were selected which covered the two worst damage areas. (See Figure 1). TMM 99, located on the lower wing glove, was chosen to simulate one of the longer damage sites, and TMM 352, located near the left main landing gear door, was chosen to cover the site of the deepest damage.

TMM 99

The impact damage analyzed in the area of TMM 99 was 6"x1"x0.75". This is one of the longer damages with significant depth (the 15" long damage was only 0.25" in depth.) The certification model 99 was modified to include a cavity 6.81"x1"x0.86" in the center of the homogeneous 3-D model. (The size difference was for convenience due to the existing node dimensions in the model.)

The tile was renodalized in the area around the hole. Refined elements on the downstream side of the hole were created to help simulate the cavity heating effects. Elements beneath the cavity were also refined.

To simulate the increased local heating due to the presence of the cavity, bump factors, provided by aeroheating, were imposed on the heating in and around the hole. Figure 3 shows the heating factors and where they were applied. The emissivity of the damaged tile surfaces was reduced to 0.5 due to the lack of black coating. Bottom sun entry interface (EI) temperatures were used for a worst case analysis.

TMM 352

TMM 352 is a large model covering the area of the lower fuselage and wing around the left main landing gear door (MLGD.) The deepest of the damage sites was analyzed using this model. Because the damage was so deep in this area and the fact that it did not penetrate to the aluminum structure dictated that the tile in the area of impact was more than 1.5" thick. The hole was placed over the frame next to the MLGD because the tile in this region is thick enough to accommodate such a deep hole. This cavity has dimensions 4"x4"x1.5".

The model was renodalized in a similar manner to the TMM 99 modification. Heating bump factors were generated for this configuration as shown in Figure 5. The 0.5 emissivity for broken tile and the bottom sun EI temperatures were also used for this analysis.

STS-89 Thermal Analysis:

The impact of potential damage on flight 89 was evaluated with two scenarios. The first was the same local damage as occurred on STS-87, and the second evaluated the potential reduction of safety margins if the STS-89 tile damage was more severe than the STS-87 experience. The local damage scenario was analyzed similar to the STS-87 analysis using TMMs 99 and 352. The more severe damage scenario was evaluated using wing/fuselage model TMM 353. Mission specific aeroheating was generated for EOM and TAL for STS-89. The 0.5 emissivity for broken tile and the bottom sun EI temperatures were used for all analyses.

TMM 99

The evaluation of STS-89 on TMM 99 utilized the same hole configuration and bump heating factors as that of STS-87. Both EOM and TAL trajectories were analyzed.

TMM 352

The location of the damage analyzed on OV-102 has a large frame attached to the underlying aluminum skin. This large mass distributed the heat well. However, there was no guarantee that damage would occur again at this benign location, and analysis of potential damage in this location would be unconservative. Therefore, a second hole location was chosen forward of the MLGD and away from the frame. The tile in this region is 1.15 inches. Two depths of this hole location were analyzed: one 4"x4"x0.5" (50% tile loss), and the other 4"x4"x1", leaving only the 0.15" densified layer of the tile. Heating factors were calculated for these two configurationsFigure 6), and both models were analyzed for the EOM and TAL trajectories.

TMM 353

Structural analysis identified temperature gradients at the bottom panel from the centerline to the side wall of the mid-fuselage bottom at Xo1050 as a critical margin area. TMM 353 was chosen to simulate extensive damage in this area. The analysis considered a 25% tile loss over one frame bay of the bottom. Within this area, one tile was reduced to 50% thickness. SeeFigure 7.

Analysis Results:

The results of the evaluations are presented inTable 1 and Figure 8 through Figure 20. The STS-87 analysis resulted in TPS surface temperatures at the damage sites just above the melting point of the material. The local structure temperature results were all below material limits.

The STS-89 evaluation of potential local damage showed that if OV-105 were to experience damage identical to that of OV-102 during STS-87, the results would be similar; over heating of tile material with structural temperatures within certification limits. However, the results of the TMM 352 analysis of hole location 2, the thinner tile, show that the structure would exceed the 350° F material limit, and debonding of the honeycomb structure in that area would be expected. Therefore, if the deep damage which occurred on the thicker tiles in the area of TMM 352 were to occur a few inches inboard, where the tiles and the structure are thinner, local structural damage would occur. The adjacent structure would be able to pick up the load with no safety of flight issue but possible structural damage.

Evaluation of extensive damage on the outboard lower surface using TMM 353 indicated minimal tile damage. However, the structural temperatures and temperature gradients exceeded acceptable limits. The temperature results of this analysis were assessed by the structures group and their conclusion was that large in-plane gradients and thermal stresses result in unacceptable margins of safety.

Conclusions:

Damage to OV-102 during STS-87 was limited to the TPS. There were no local temperatures exceeding structural temperature limits, and no safety margins were violated. STS-87 severity of impacts on OV-105 during STS-89 would have safe vehicle return but with the possibility of local structural damage.

Potential STS-89 damage more severe than that on experienced on STS-87 could significantly degrade safety margins. The wider area of impact damage assessed on the bottom panels resulted in unacceptable margins.

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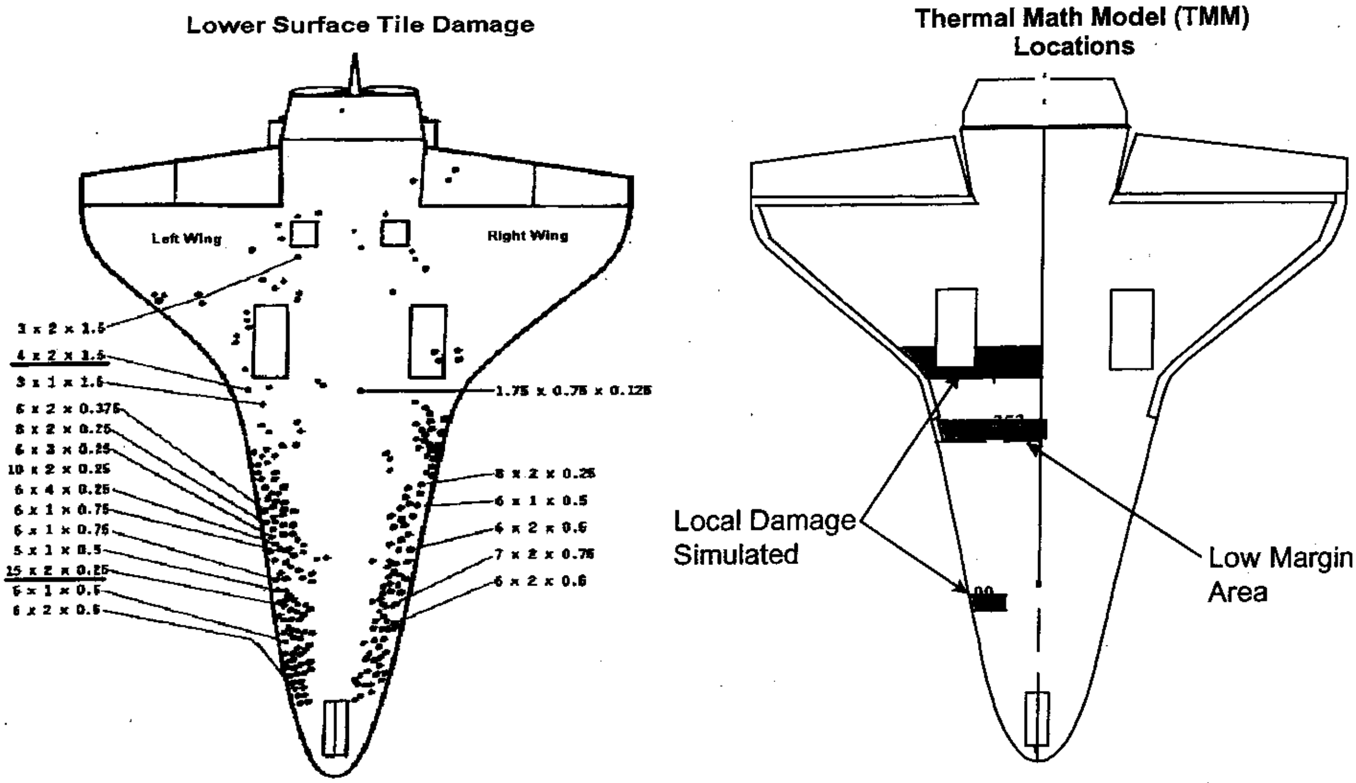


Figure 1 - Model Locations Chosen to Analyze Worst Damage Sites

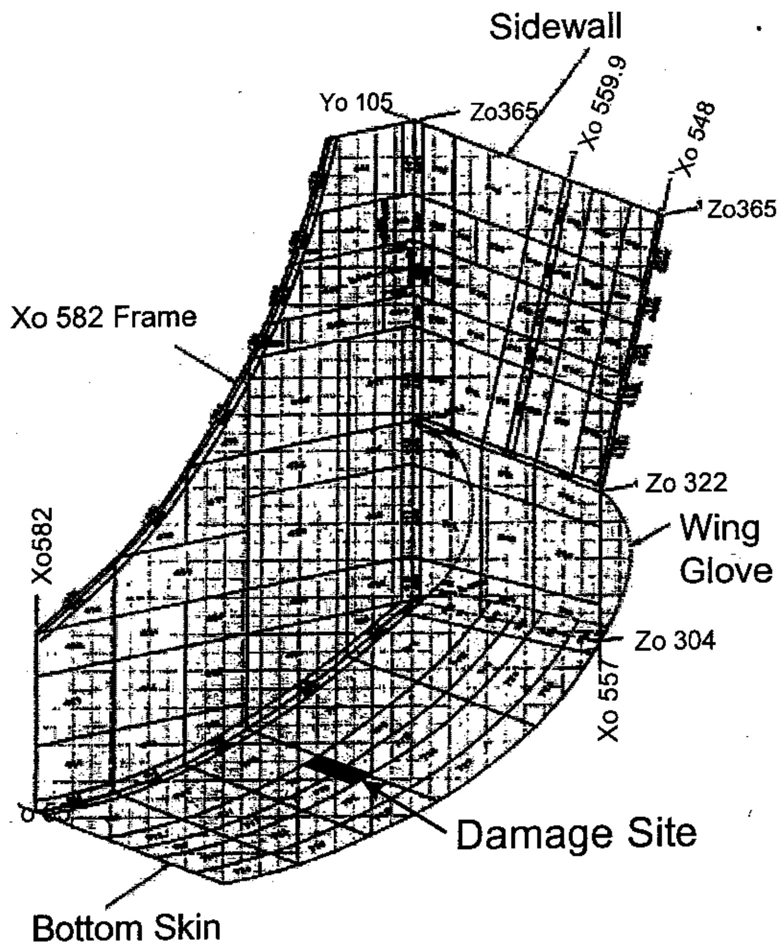


Figure 2 - Nodal Diagram of TMM 99 Structure

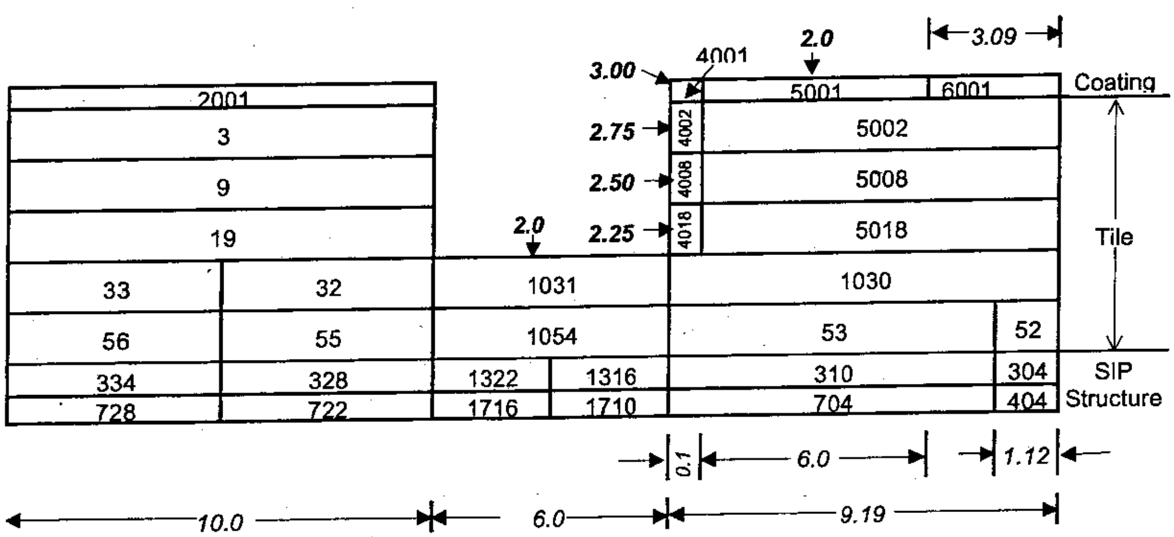


Figure 3 - Cross Section Nodal Diagram of TMM 99
(Heating Bump Factors in Bold Face Type)

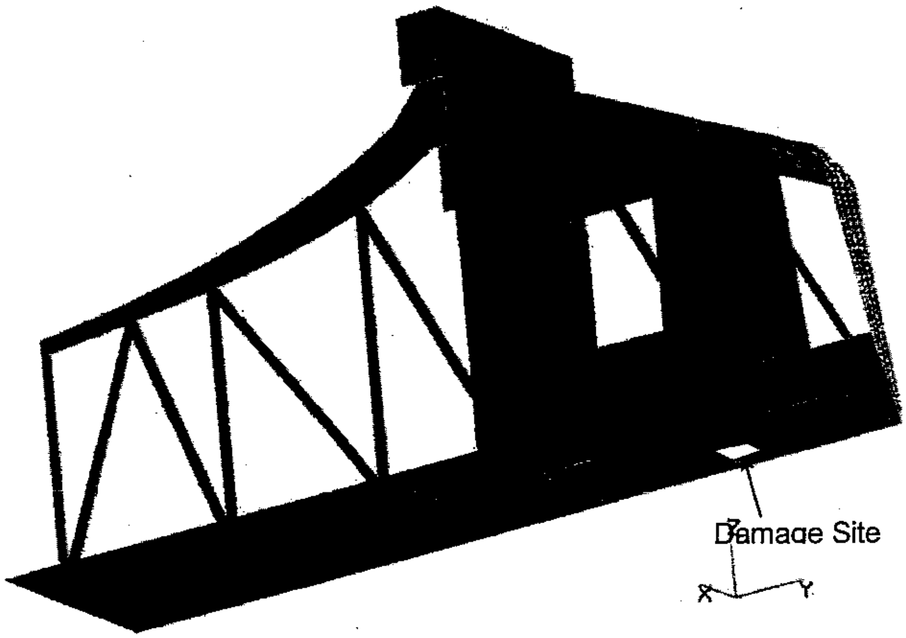


Figure 4 - TMM 352 Structure

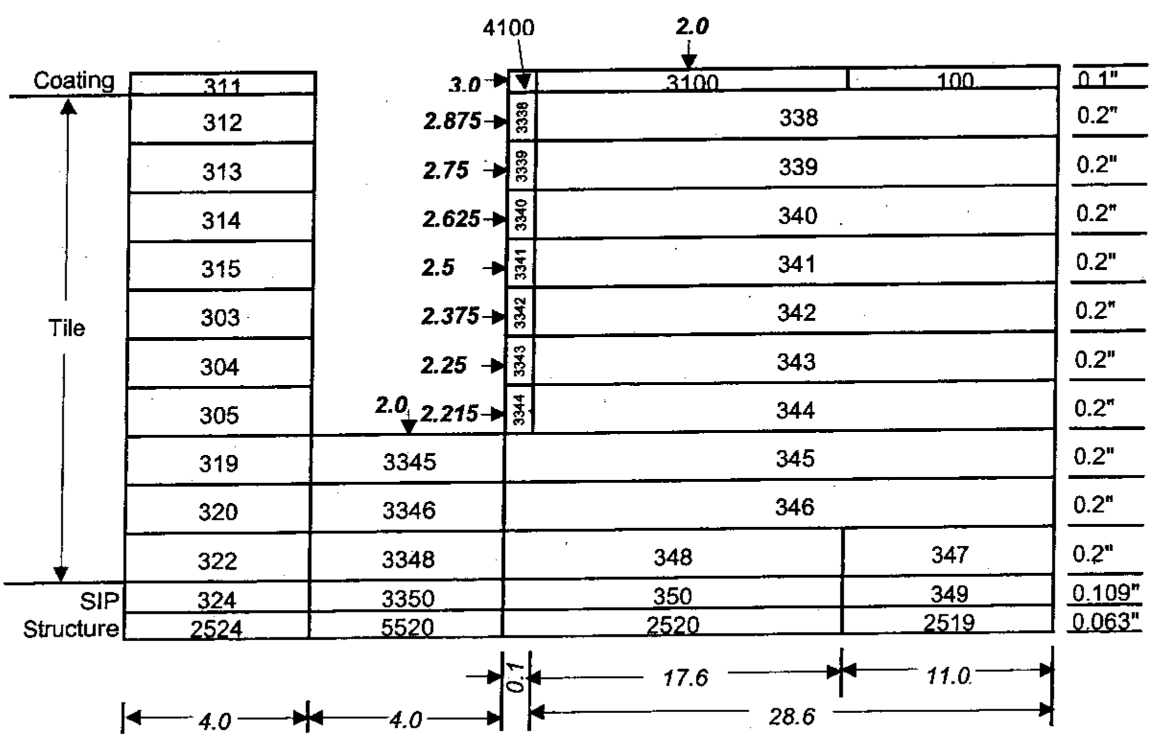
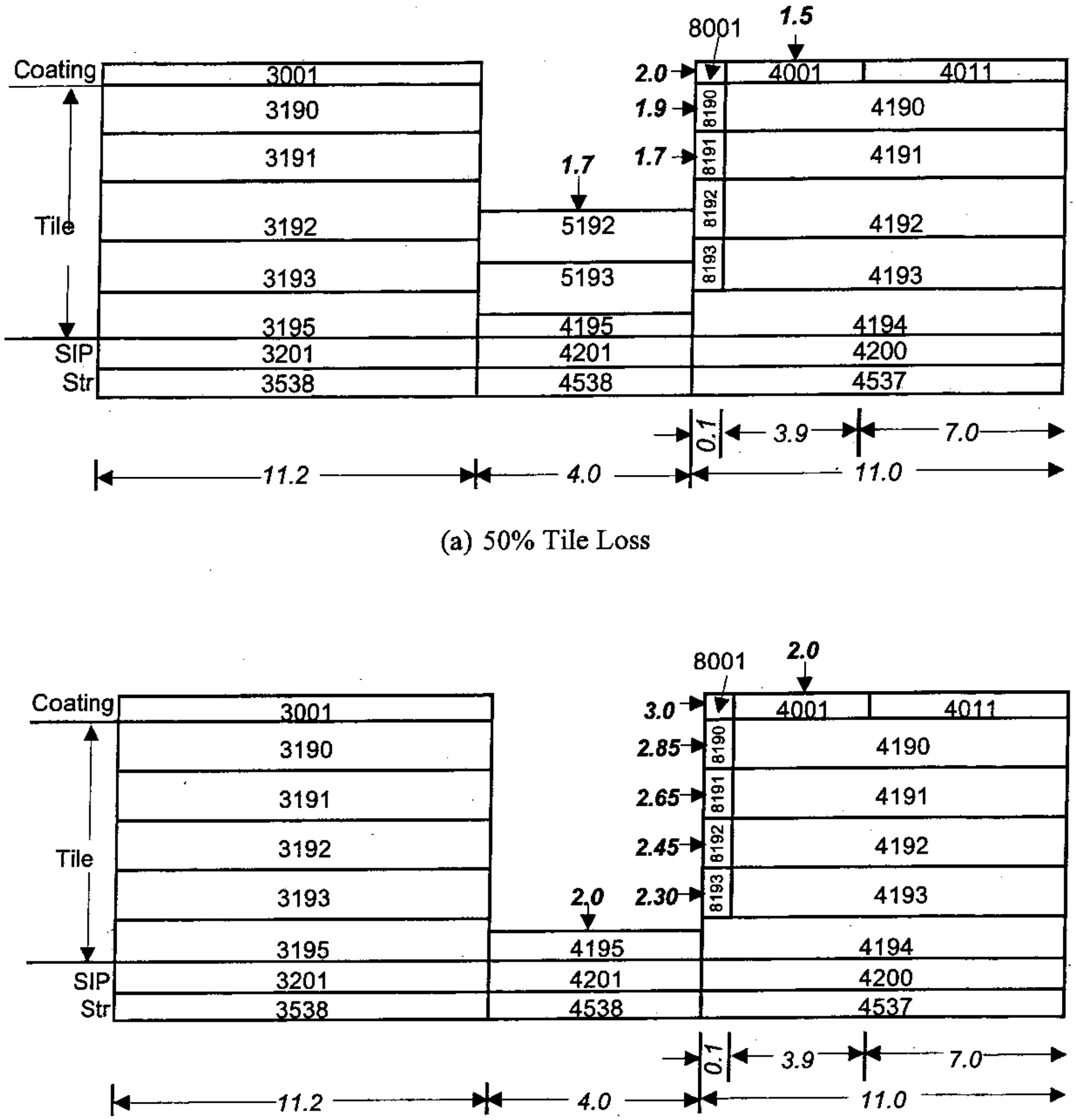


Figure 5 - Cross Section Nodal Diagram of Hole Location 1 of TMM 352 (Heating Bump Factors in Bold Face Type)



(a) 50% Tile Loss

(b) Loss to Densified Layer

Figure 6 - Cross Section Nodal Diagram of Hole Location 2 of TMM 352 (Heating Bump Factors in Bold Face Type)

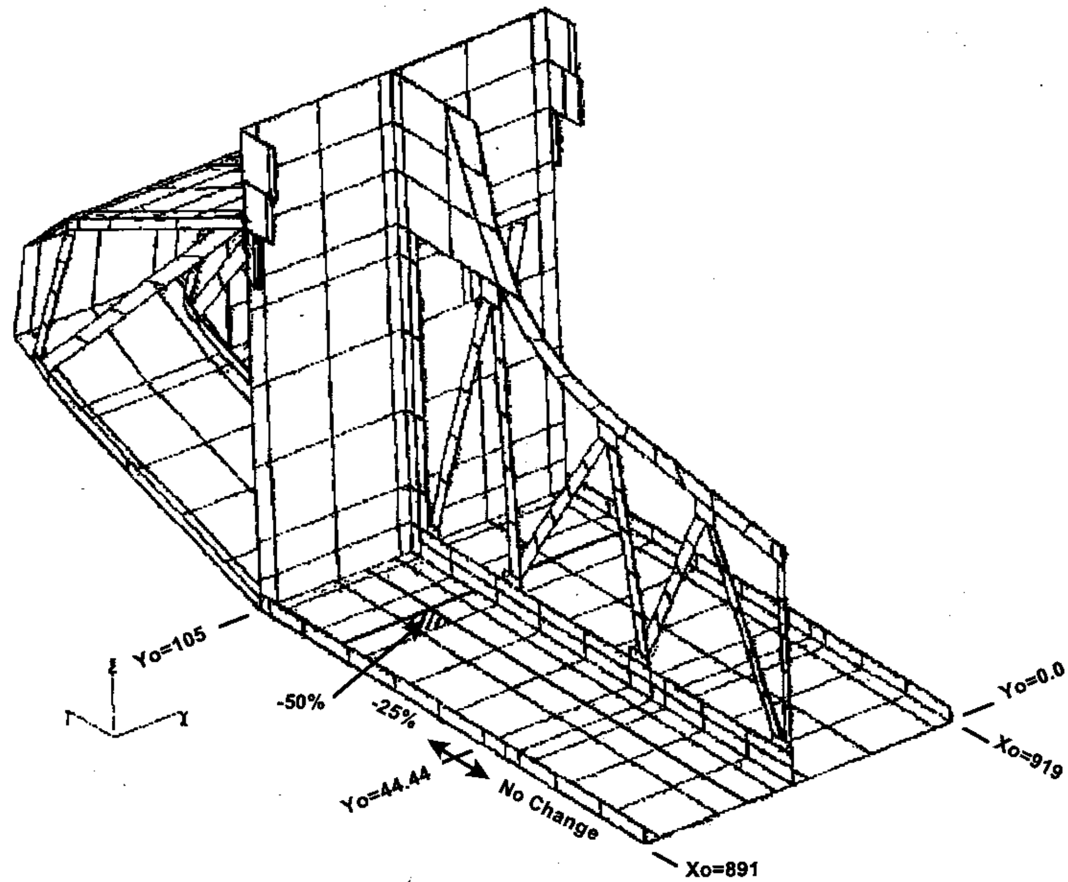


Figure 7 - Simulated Damage Location on TMM 353

Table 1 - Maximum Surface and Structure Temperatures for STS-87 Analysis

			Maximum Temperatures (°F)					
			STS-87 EOM		**STS-89 EOM**		**STS-89 TAL**	
Model	Cavity Size	Damage Description	Surface	Structure	Surface	Structure	Surface	Structure
TMM 99	6.8"x1"x0.86"	STS-87 Damage	2940	293	2988	293	3500	211
TMM 352 2.2" Tile	4"x4"x1.5"	STS-87 Damage	2878	123/280*	3109	109/125*	3363	245/287*
1.15" Tile	4"x4"x0.5"	50% Tile Loss	2621	309	2315	317	-	-
1.15" Tile	4"x4"x1.0"	Loss to Densified	2927	485	3162	505	3040	435

* Structure node beneath cavity / Hottest structure node

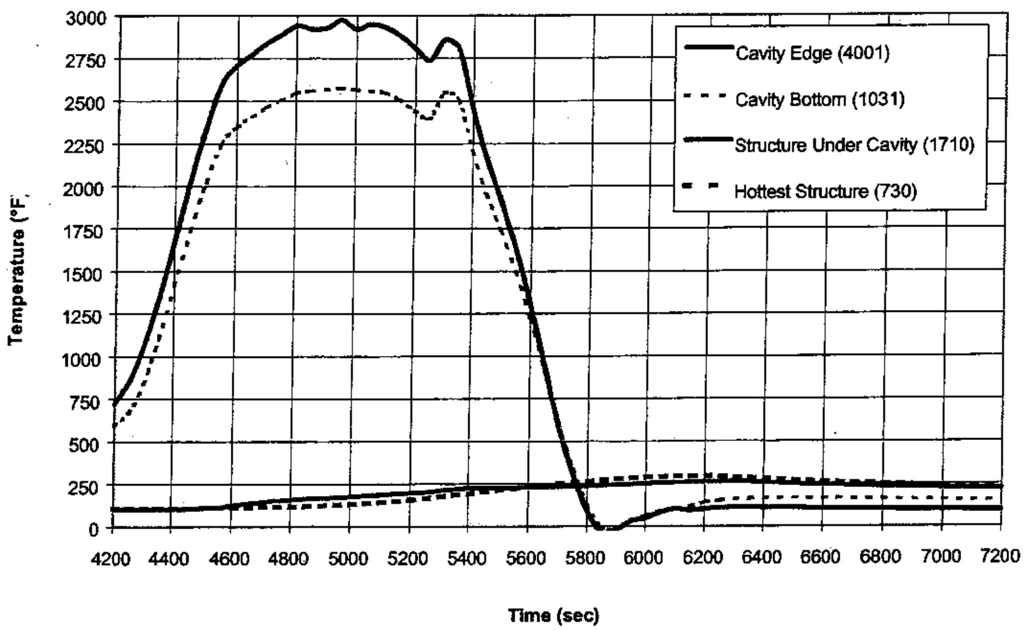


Figure 8 - STS-87 Temperature Results for TMM 99

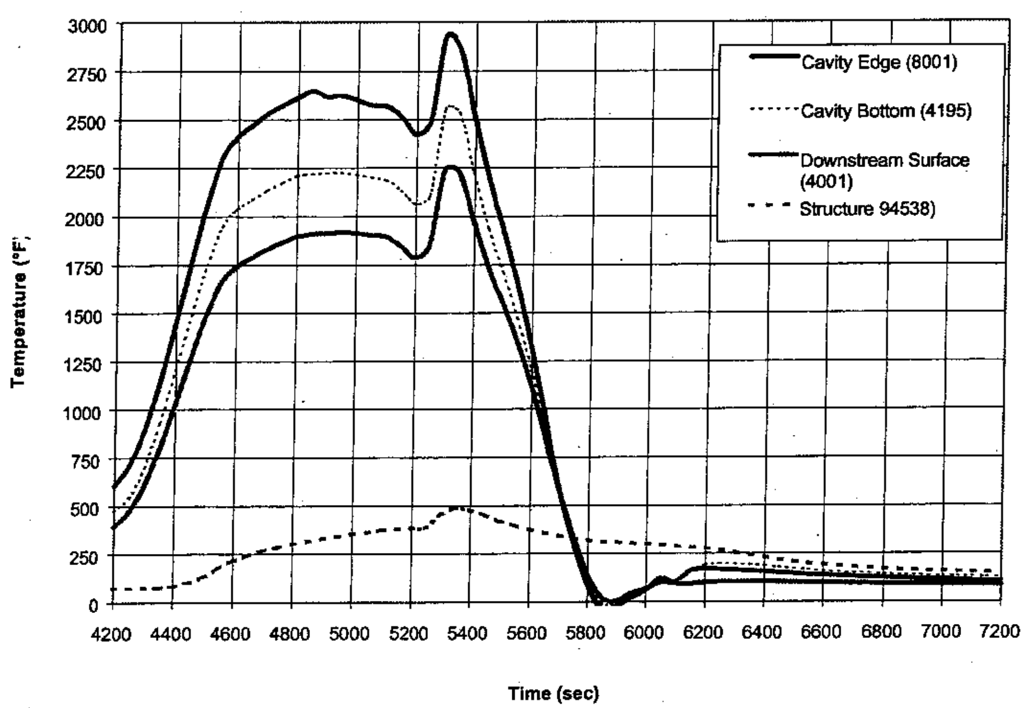


Figure 9 - STS-87 Temperature Results for TMM 352 Hole Location 1

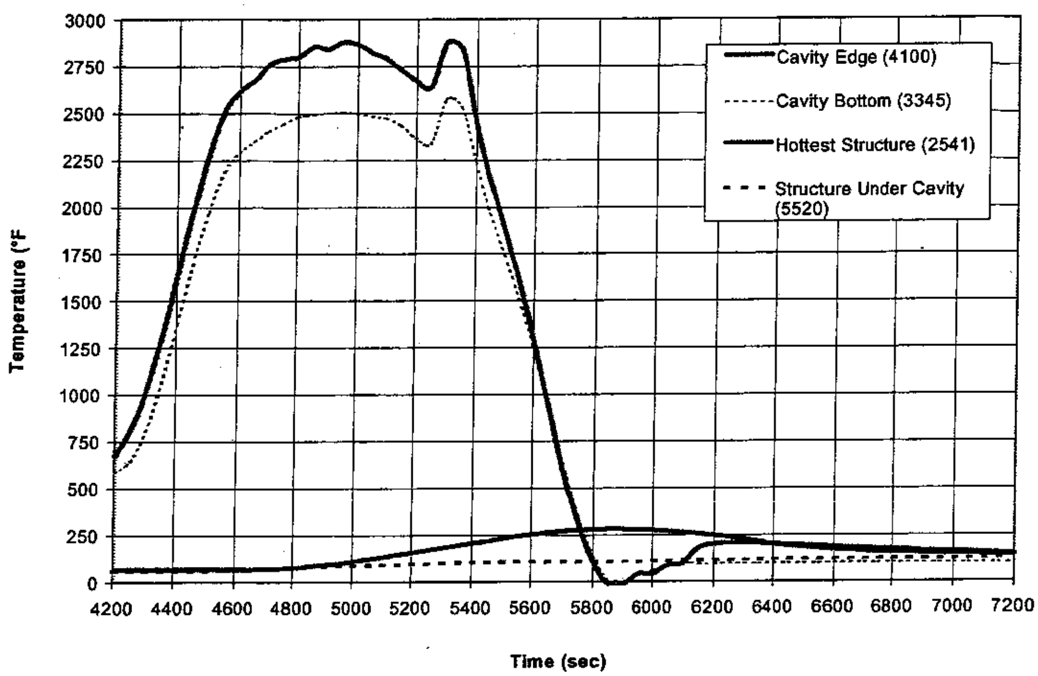


Figure 10 - STS-87 Temperature Results for TMM 352 Hole Location 2 (50% Tile Loss)

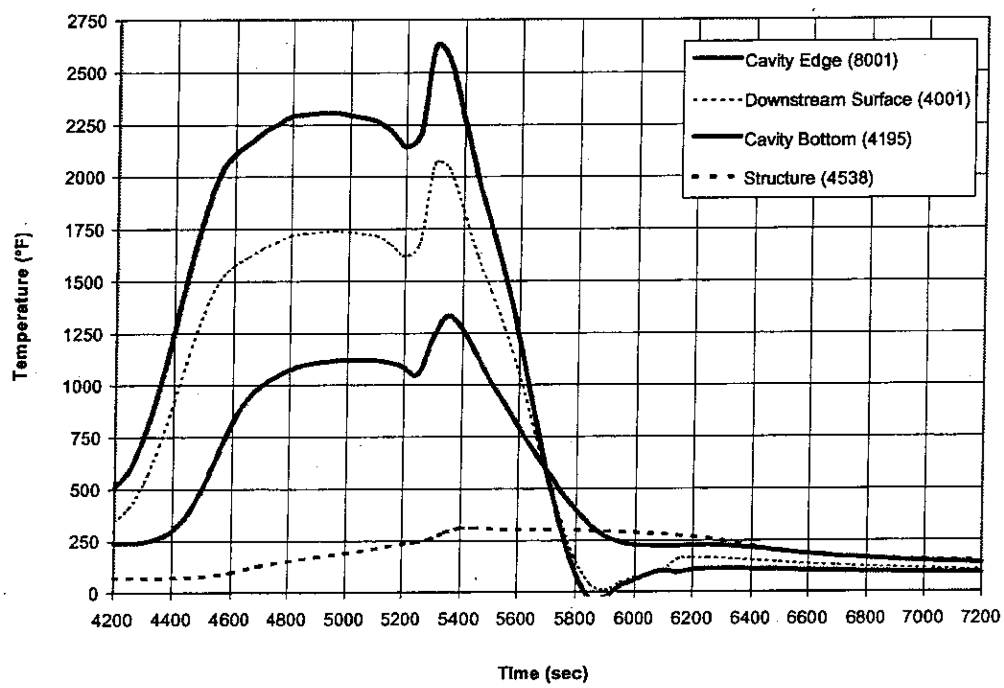


Figure 11 - STS-87 Temperature Results for TMM 352 Hole Location 2 (Loss to Densified Layer)

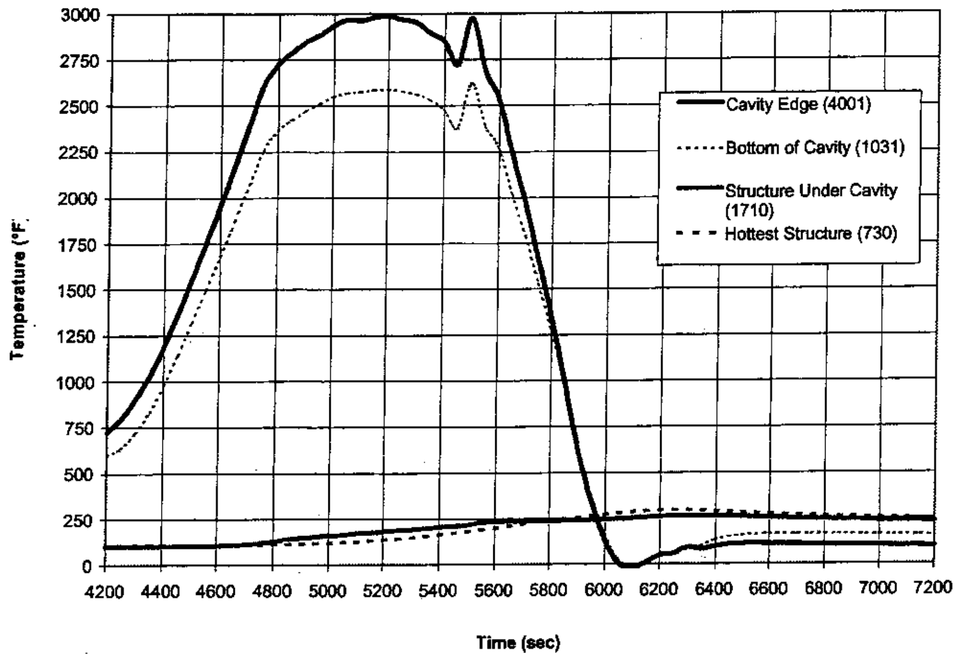


Figure 12 - STS-89 EOM Temperature Results for TMM 99

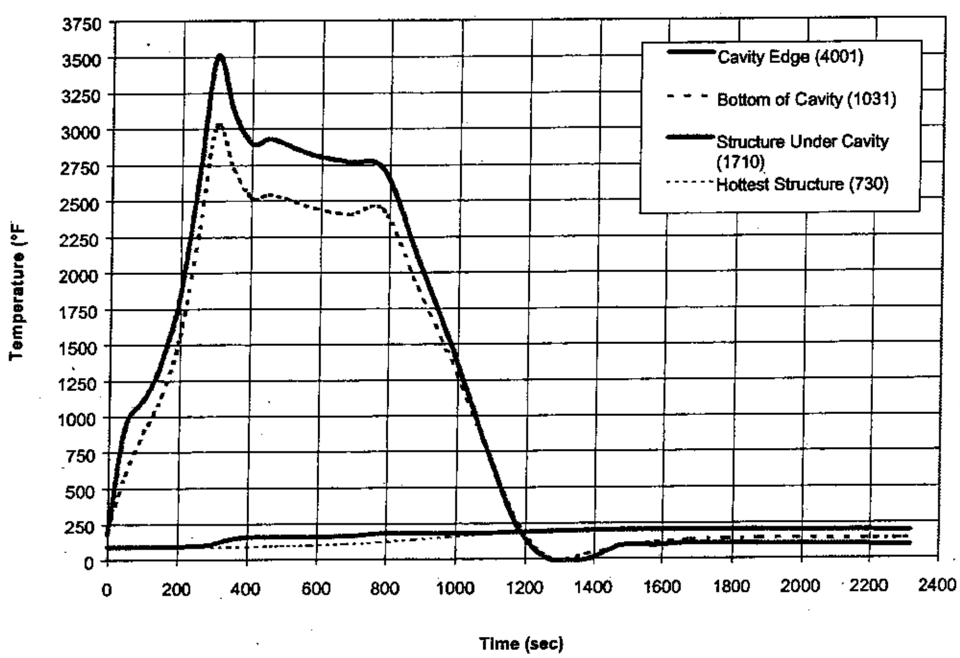


Figure 13 - STS-89 TAL Temperature Results for TMM 99

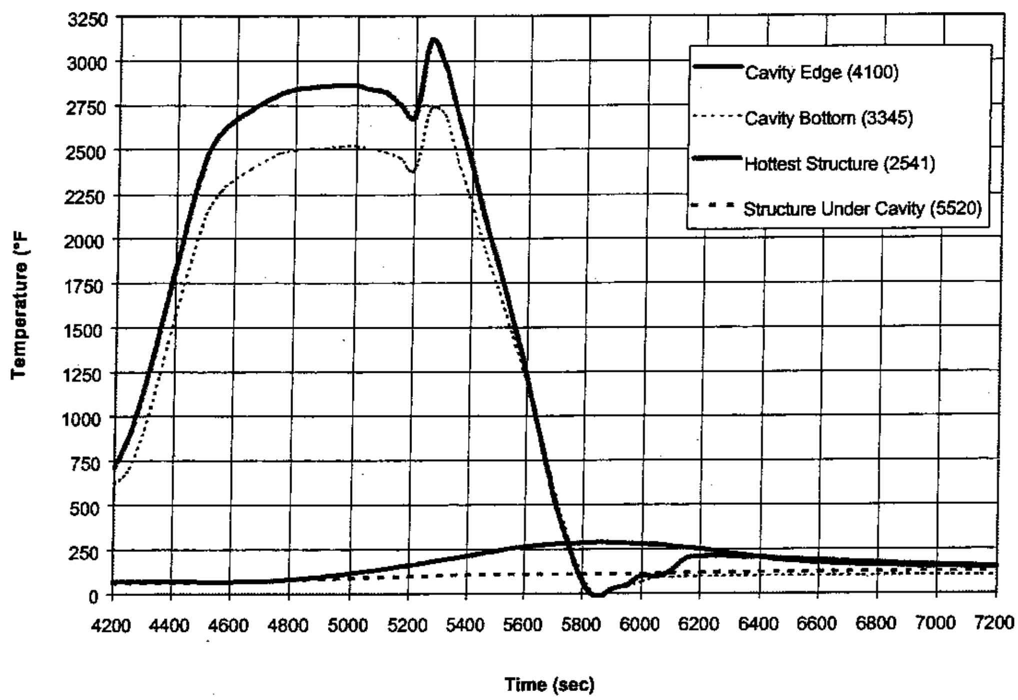


Figure 14 - STS-89 EOM Temperature Results for TMM 352 Hole Location 1

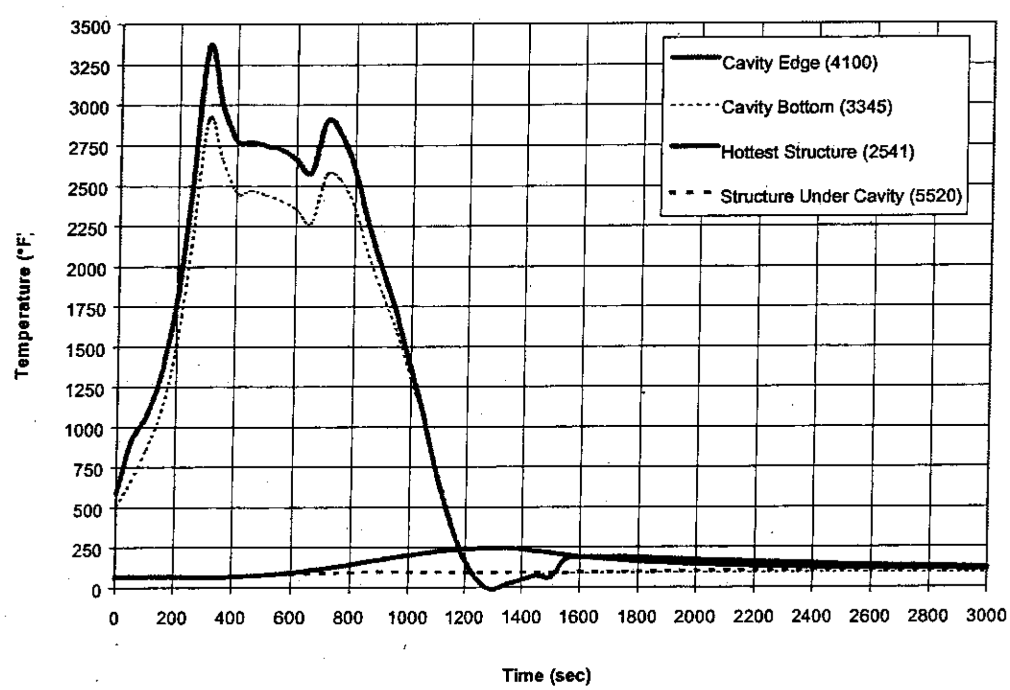


Figure 15 - STS-89 TAL Temperature Results for TMM 352 Hole Location 1

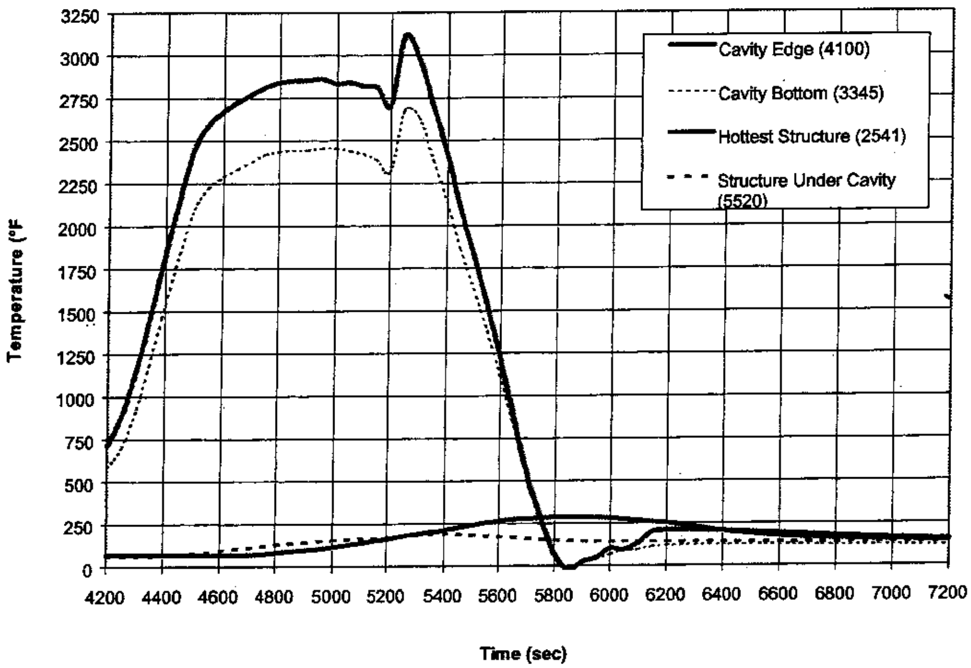


Figure 16 - STS-89 EOM Temperature Results for TMM 352 Hole Location 1 (Loss to Densified Layer)

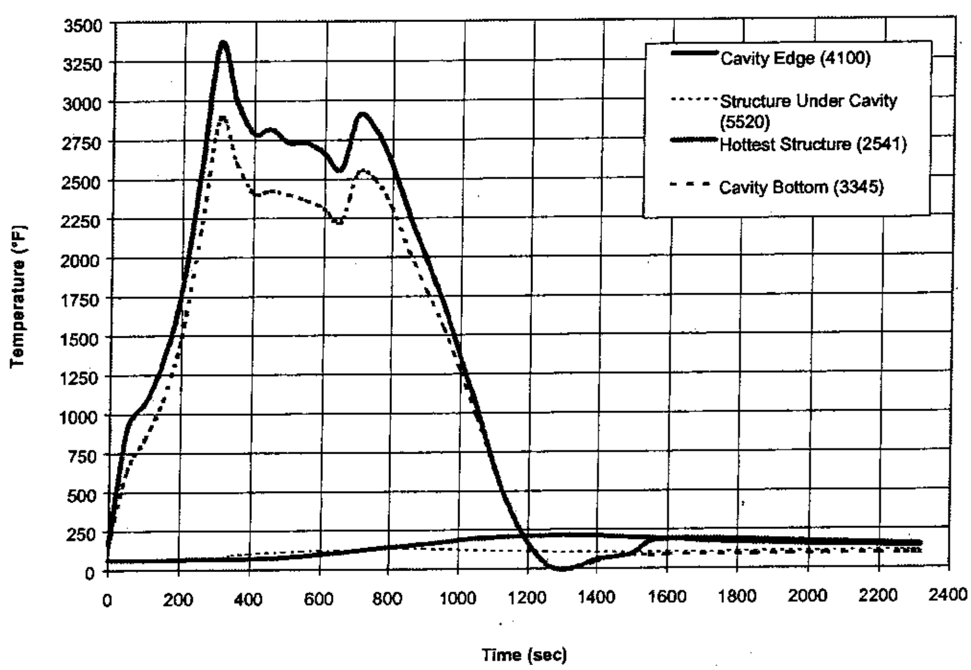


Figure 17 - STS-89 TAL Temperature Results for TMM 352 Hole Location 1 (Loss to Densified Layer)

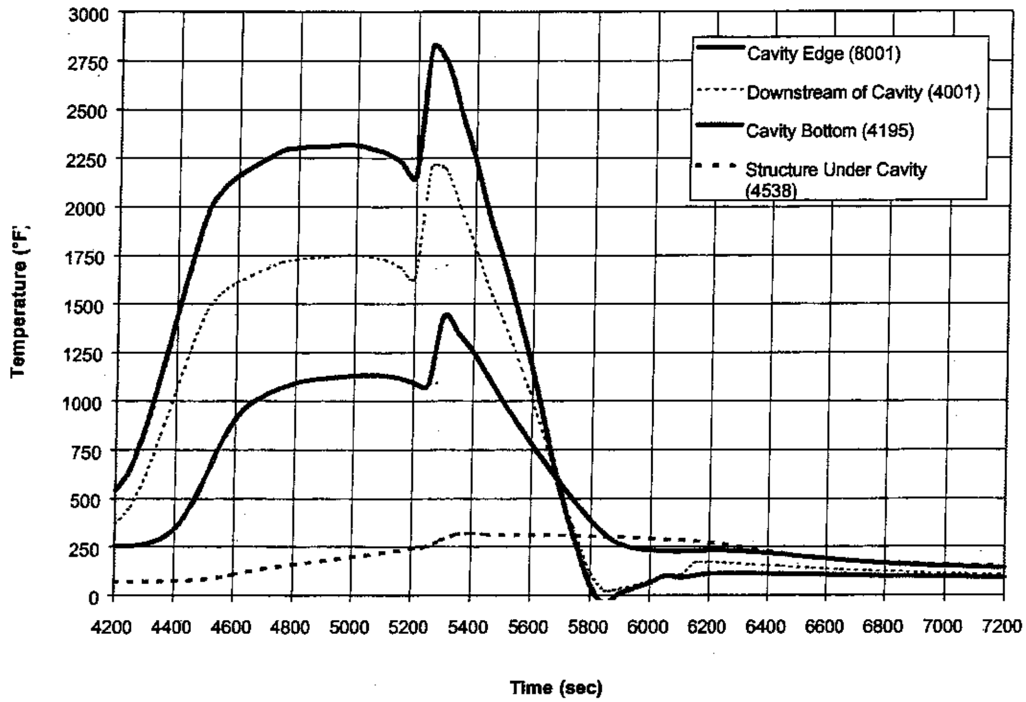


Figure 18 - STS-89 EOM Temperature Results for TMM 352 Hole Location 2 (50% Tile Loss)

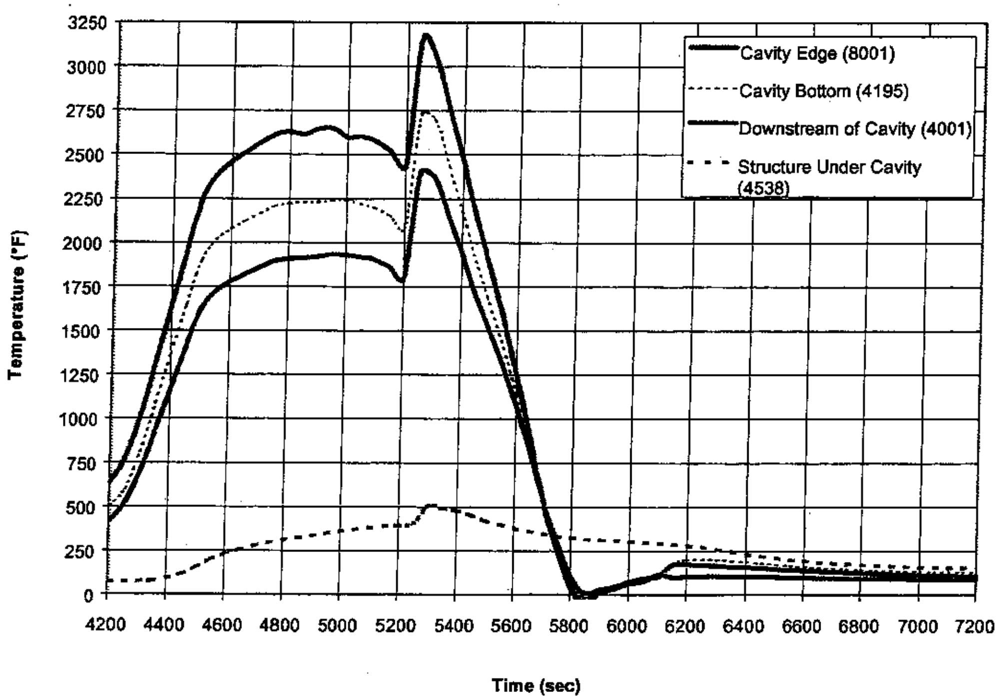


Figure 19 - STS-89 EOM Temperature Results for TMM 352 Hole Location 2 (Loss to Densified Layer)

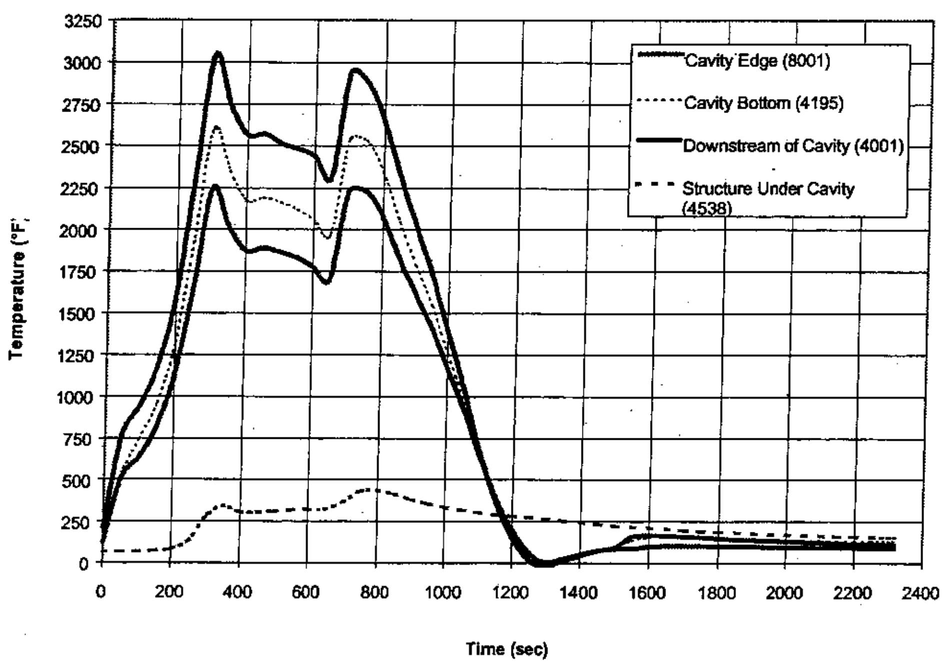


Figure 20 - STS-89 TAL Temperature Results for TMM 352 Hole Location 2 (Loss to Densified Layer)

Michele Lewis

From:	CURRY, DONALD M. (JSC-ES3) (NASA)
Sent:	Tuesday, January 21, 2003 12:23 PM
To:	RICKMAN, STEVEN L. (JSC-ES3) (NASA); KOWAL, T. J. (JOHN) (JSC-ES3) (NASA)
Subject:	RCC Damage Threshold

Attached are charts showing RCC damage threshold due to impact.

RCC damage threshold2.pdf

Don C